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OCEANOGRAPHIC AND ACOUSTICAL PROPERTIES OF ATLANTIC AREA C1 DUR--ETC(U)
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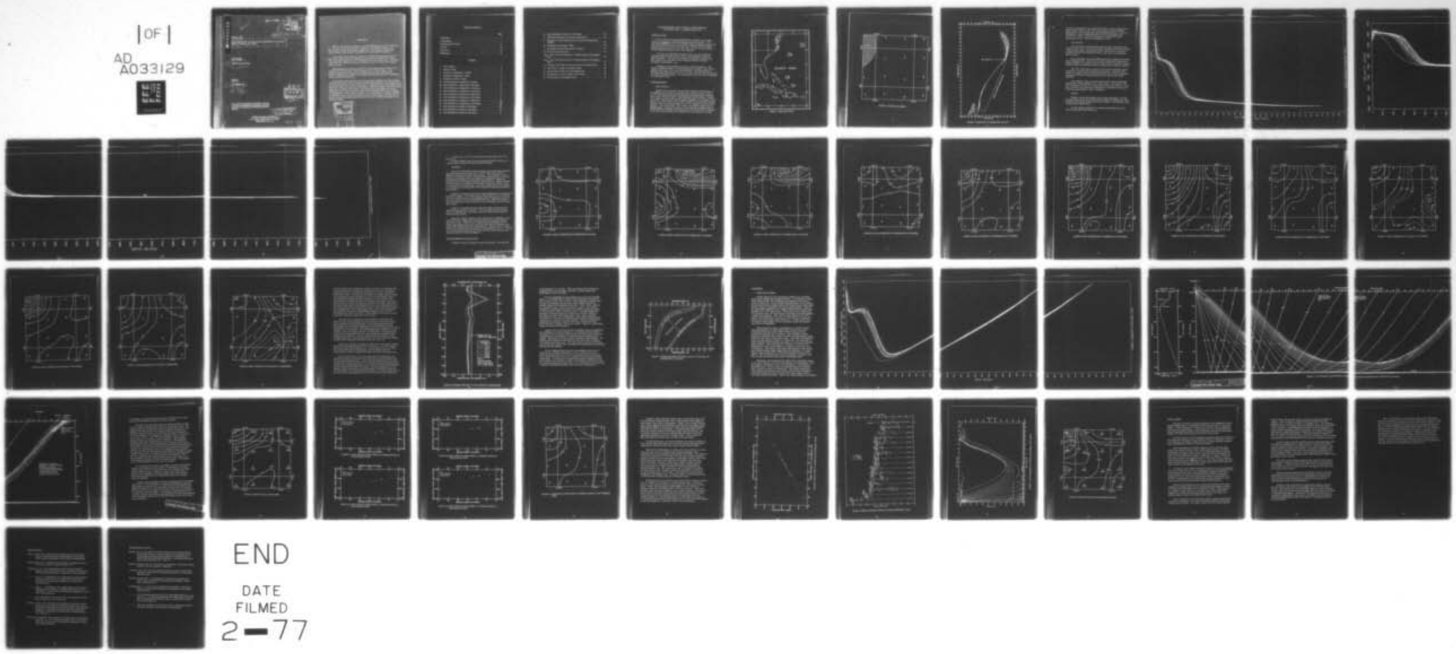

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OCEANOGRAPHIC AND ACOUSTICAL PROPERTIES OF ATLANTIC AREA C_1 DURING JUNE 1963

AUTHOR

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DATE

(11) DEC 1965

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MARINE SCIENCES DEPARTMENT
U. S. NAVAL OCEANOGRAPHIC OFFICE
WASHINGTON 25, D.C.

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ABSTRACT

Sixteen oceanographic stations, obtained during a one-week period from 23 - 30 June 1963 in a one-degree square by the USS SAN PABLO, were analyzed for spatial and temporal variations. The analysis of this deep water Atlantic area revealed variations of an unsuspected magnitude.

At the time of the survey, a large gyre entered the northwest corner of the area and raised the 12° isotherm of one northwest station 280 meters above the mean depth of the 12° isotherm for the rest of the area. The gyre caused the 12° isotherms of nearby stations to vary as much as 80 meters from the mean.

Bathythermogram analysis showed a normal temperature change at 30 meters of 0.1°C per hour, with an extreme of 3.0°C in 5 hours. The extreme change was caused by a structural change in the thermocline. Spatial variations were found to be considerably greater than time variations in the seasonal thermocline.

In the North Atlantic there is a layer of nearly isothermal water between 100 and 300 meters, which produces a slight sound channel. If a sound source is located in this layer, more sound will be refracted into the convergence zone than if the source is located at the surface. Minimum range to the convergence zone may be related to the depth of the permanent thermocline; however, variations of the seasonal thermocline add an additional 1000-yard variation to computations of the minimum range. The total difference between stations in minimum range to the convergence zone was 5000 yards, but exclusive of the two extreme northwest stations there was still a 2000-yard difference in minimum range.

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OCEANOGRAPHIC AND ACOUSTIC PROPERTIES OF ATLANTIC AREA C_1 DURING JUNE 1963

INTRODUCTION

The ~~U. S.~~ Naval Oceanographic Office selected four oceanic laboratory sites in the Atlantic Ocean for intensified study. The areas selected were (one-degree squares) are shown in Figure 1. Area C_1, with which this report is concerned, was surveyed by the USS SAN PABLO (AGS-30) from 23 to 30 June 1963. Sixteen Nansen stations and 98 bathythermograph traces were obtained.

The area was originally selected because it was considered oceanographically quiet, and the survey was designed to evaluate this assumption. The area was found to be dynamic in nature, and this report is an evaluation of the variations and the resultant acoustical implications.

A diagram of the station locations is given in Figure 2. The station spacing provides a relatively intensive coverage of the oceanography of the area. The area marked Region 1 displayed distinct oceanographic differences from the rest of the area and will be referred to as the northwest portion. The remainder of the area will be referred to as "Sargasso Sea".

OCEANOGRAPHY

Water Masses

Figure 3 is a composite temperature-salinity (T-S) diagram of all stations taken in area C_1 with the water masses labeled. Above 18.5°C, the curves spread out individually reflecting local conditions in the upper layers of water. North Atlantic Central Water, a water mass common in the whole North Central Atlantic, lies between 18.5°C and 4.0°C. Water below 4°C is North Atlantic Deep and North Atlantic Bottom Water; no differentiation will be made between these two water masses. The area marked "18°C water" is a feature common to the Sargasso Sea. It has been defined as water having a limited range of temperature and salinity with values near 18°C and 36.5°/oo, respectively, and it is isothermal and isohaline for some interval of depth.

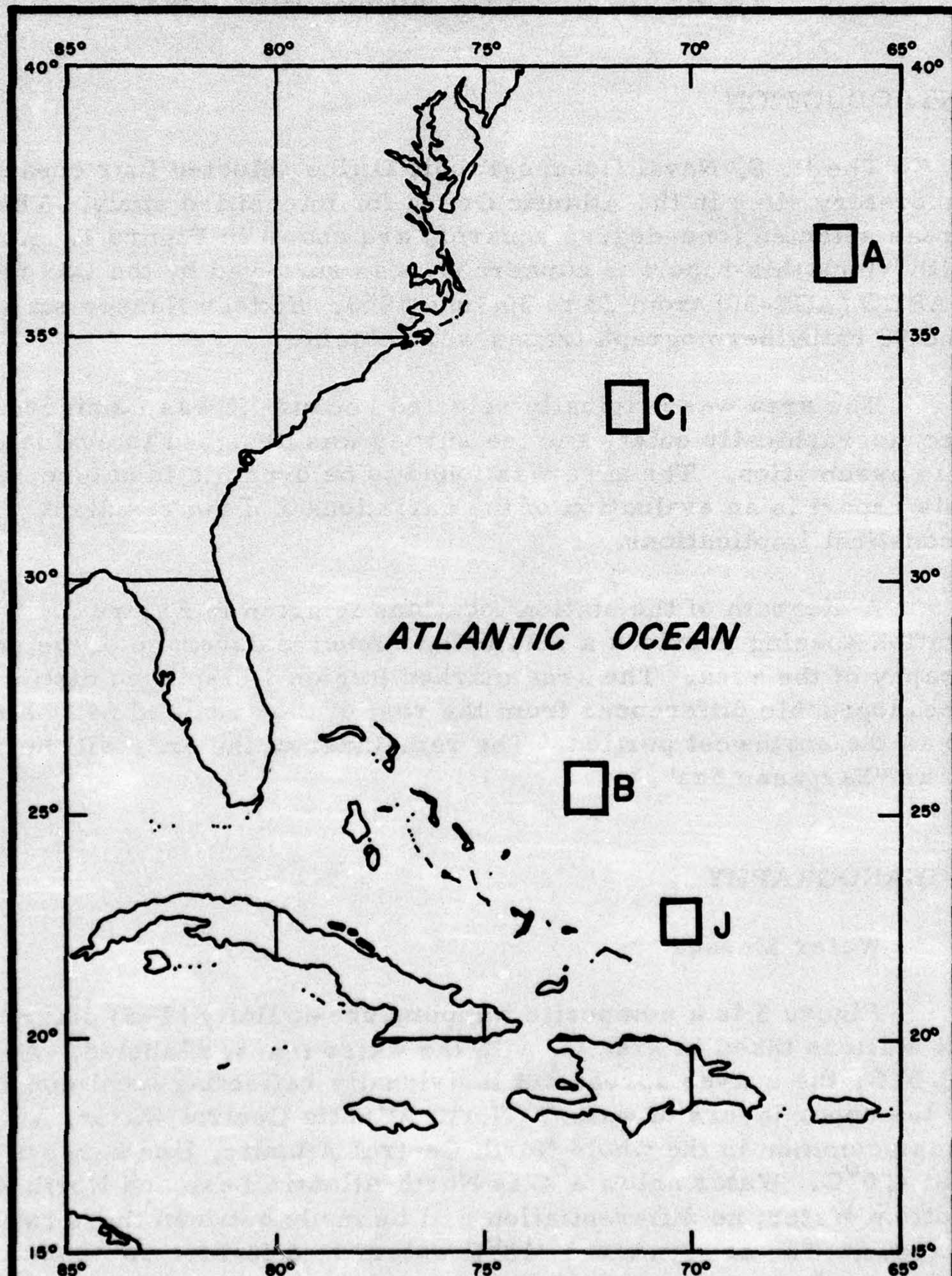


FIGURE 1 AREA LOCATIONS

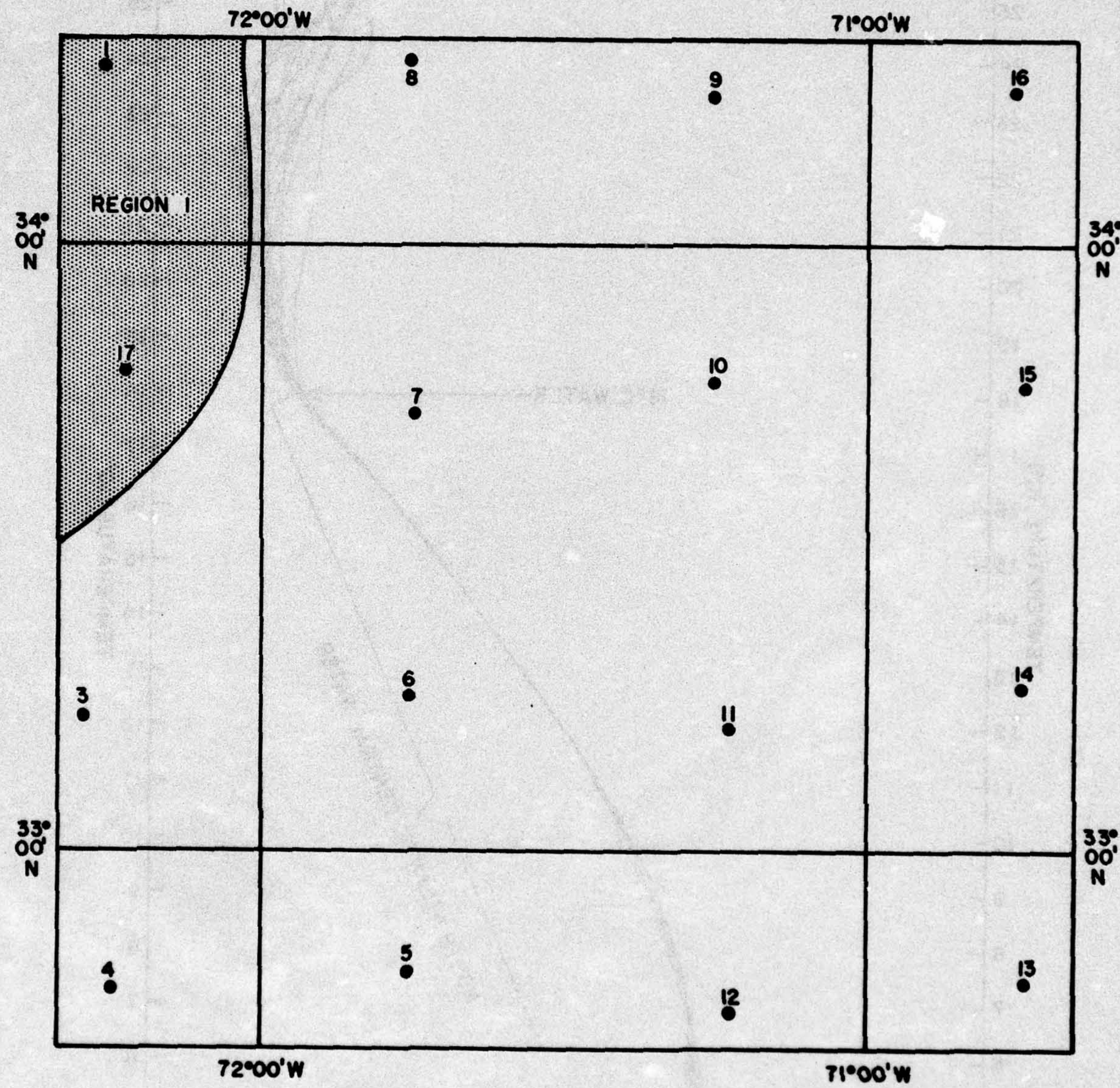


FIGURE 2 STATION LOCATIONS

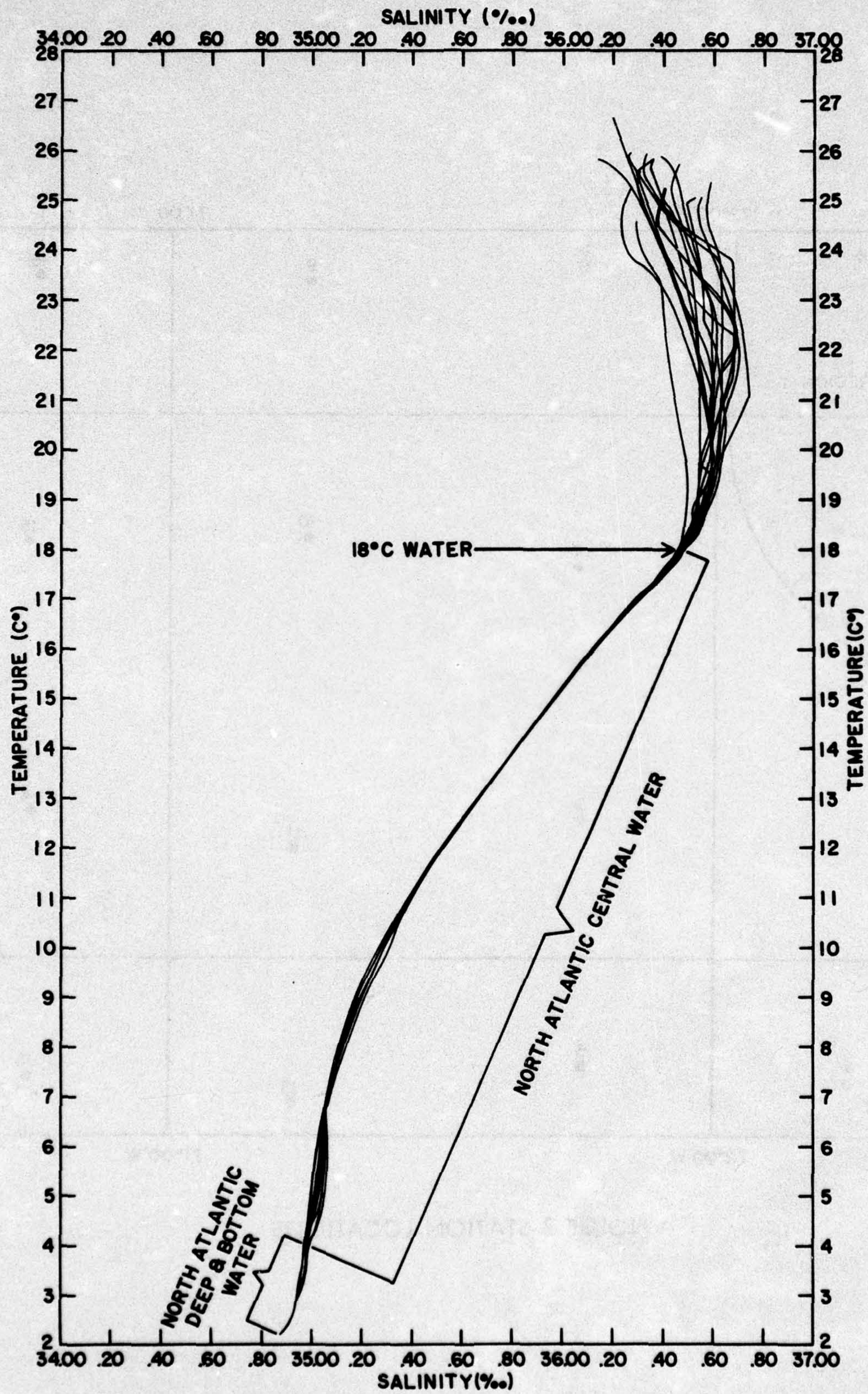


FIGURE 3 COMPOSITE OF TEMPERATURE-SALINITY

In area C_1 this interval was about 100 meters. On the temperature-depth graph, Figure 4, the 18°C water appears as the inflection point between the seasonal and permanent thermoclines. In area C_1 this type of water is characterized by 18.5°C temperature and 36.55 ‰ salinity. It will be referred to as the 18°C water. (Schroeder, et al., 1959 and Worthington, 1959.)

Temperature

The temperature-depth profiles (Fig 4) are a composite of all stations in the area. The main grouping of profiles are representative of the stations taken in the Sargasso Sea, while the two anomolous profiles are from the northwest portion, and may be of a different kind of water.

It is interesting to note the differences in the profiles representing the Sargasso Sea. Most of the seasonal thermoclines (the upper sharp gradient) are at about the same depth with the exception of three profiles which are probably caused by strong local mixing or heating.

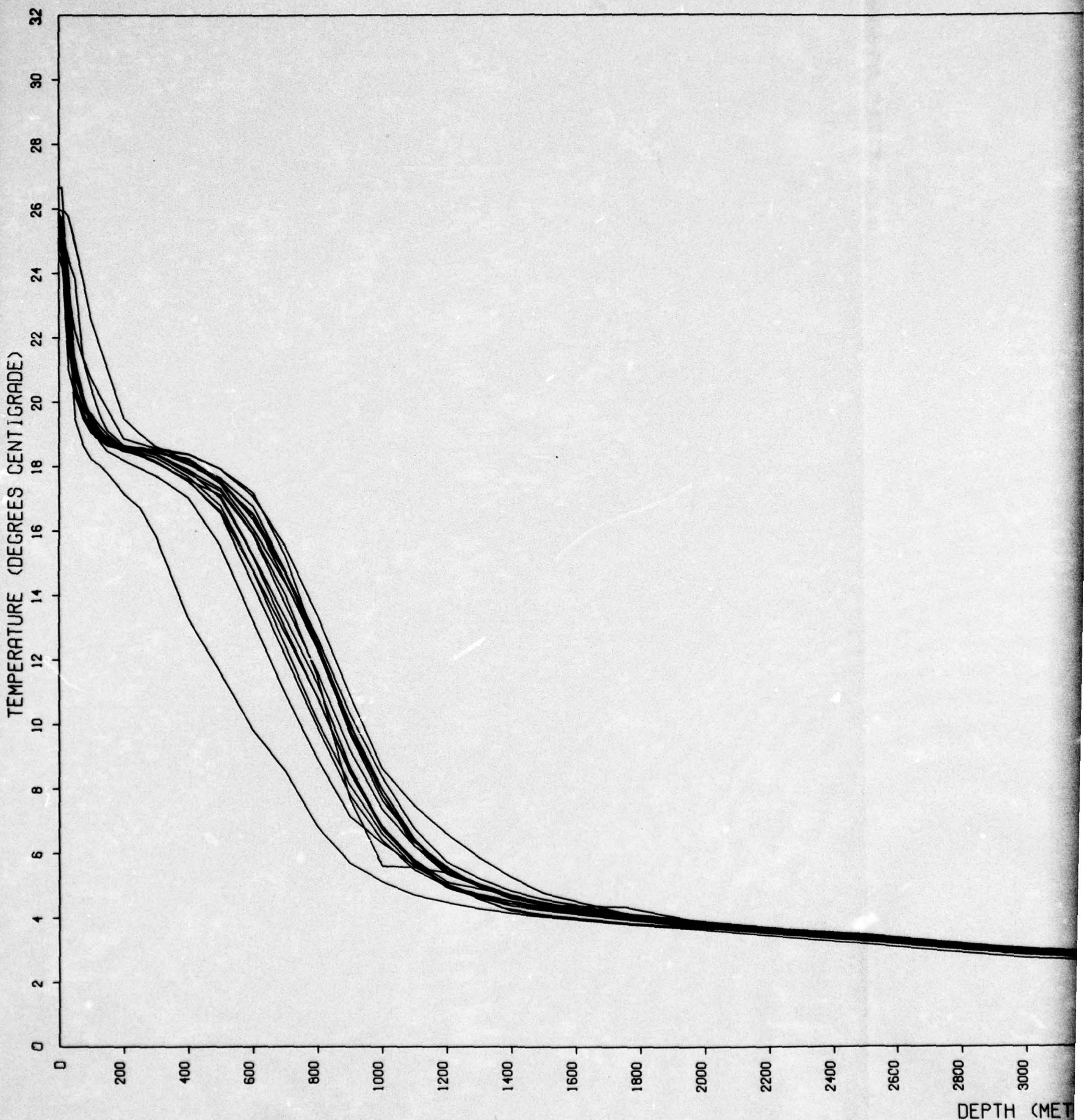
The 18°C water layer is shown by the nearby isothermal layer between the seasonal and permanent thermocline. Since the 18°C water is a feature unique to the Sargasso Sea, it is a way of identifying Sargasso Water as against other kinds of water in the North Atlantic.

Any isotherm in the permanent thermocline varies with depth between the various stations over a wide range. For example, the 12°C isotherm varies over a depth range of about 150 meters. From this composite one cannot tell whether these variations in depth are caused by geographical or time variations.

Salinity

Figure 5 shows the salinity versus depth composite. As with the temperatures, the two northwestern stations fall outside the main grouping of the other stations above 1200 meters. The features of the salinity-depth profiles are:

1) The surface salinity is lower than that directly below the surface (common in the summer),


TEMPERATURE (DEGREES CENTIGRADE)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
DEPTH (MET

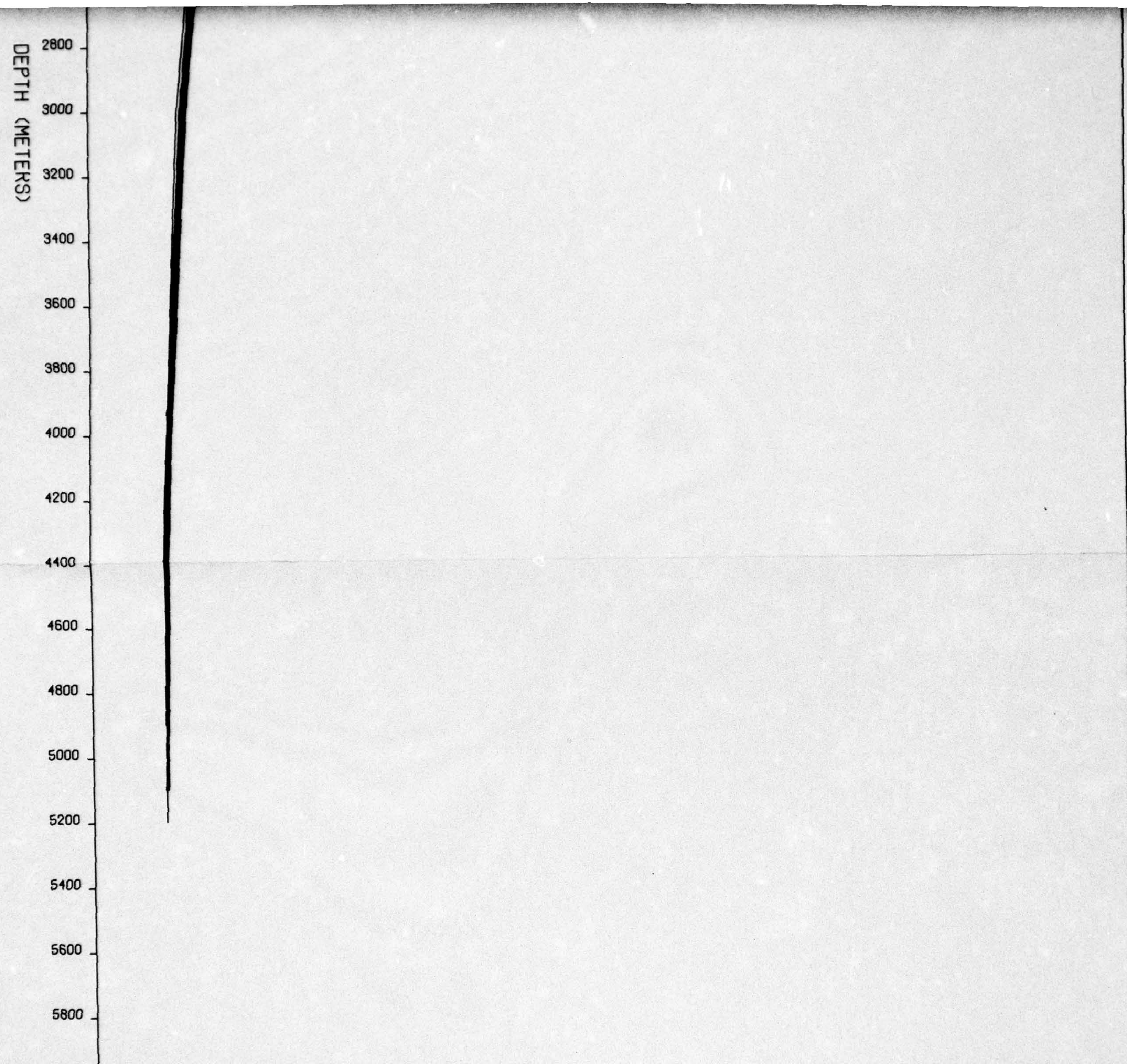
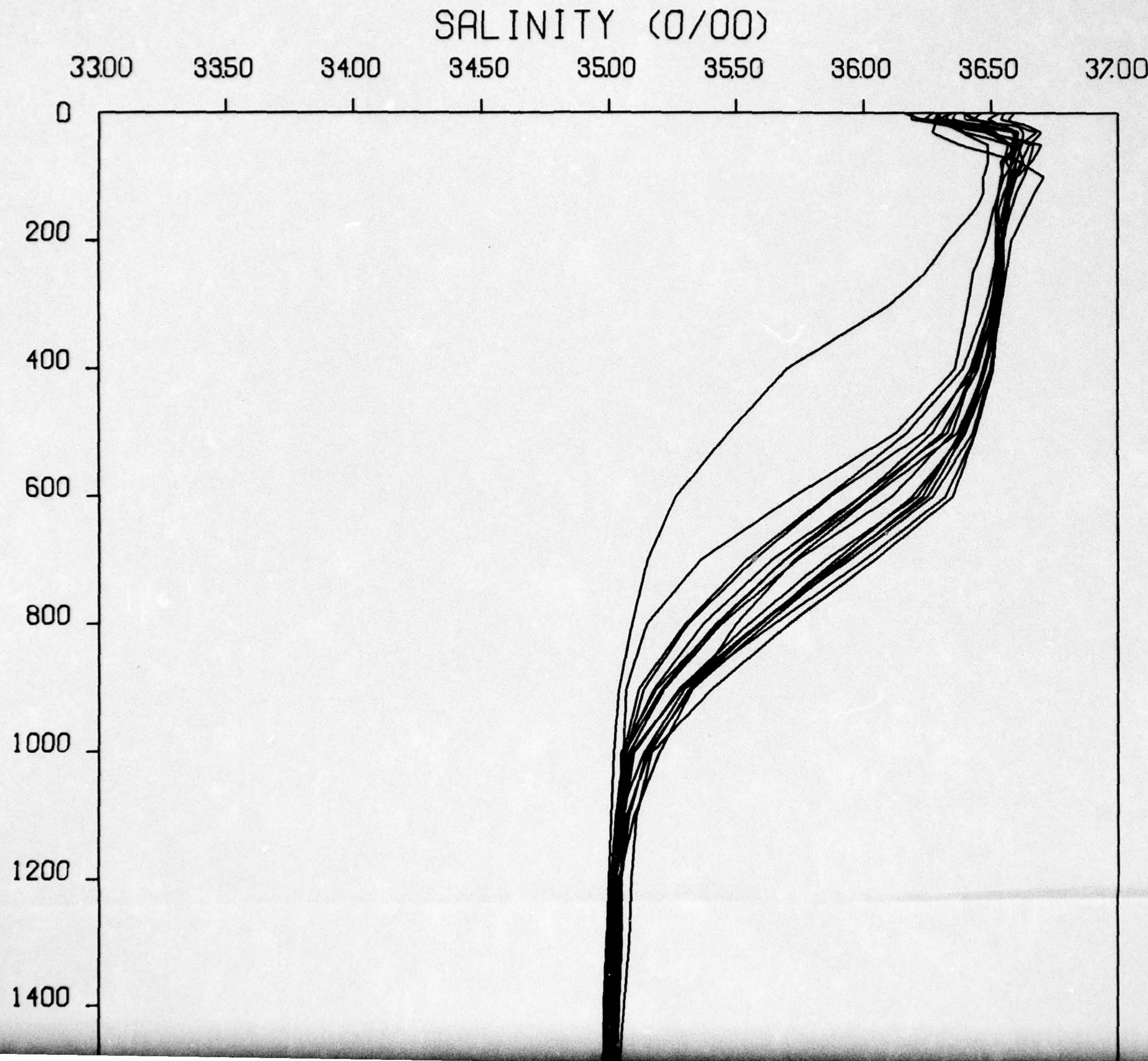
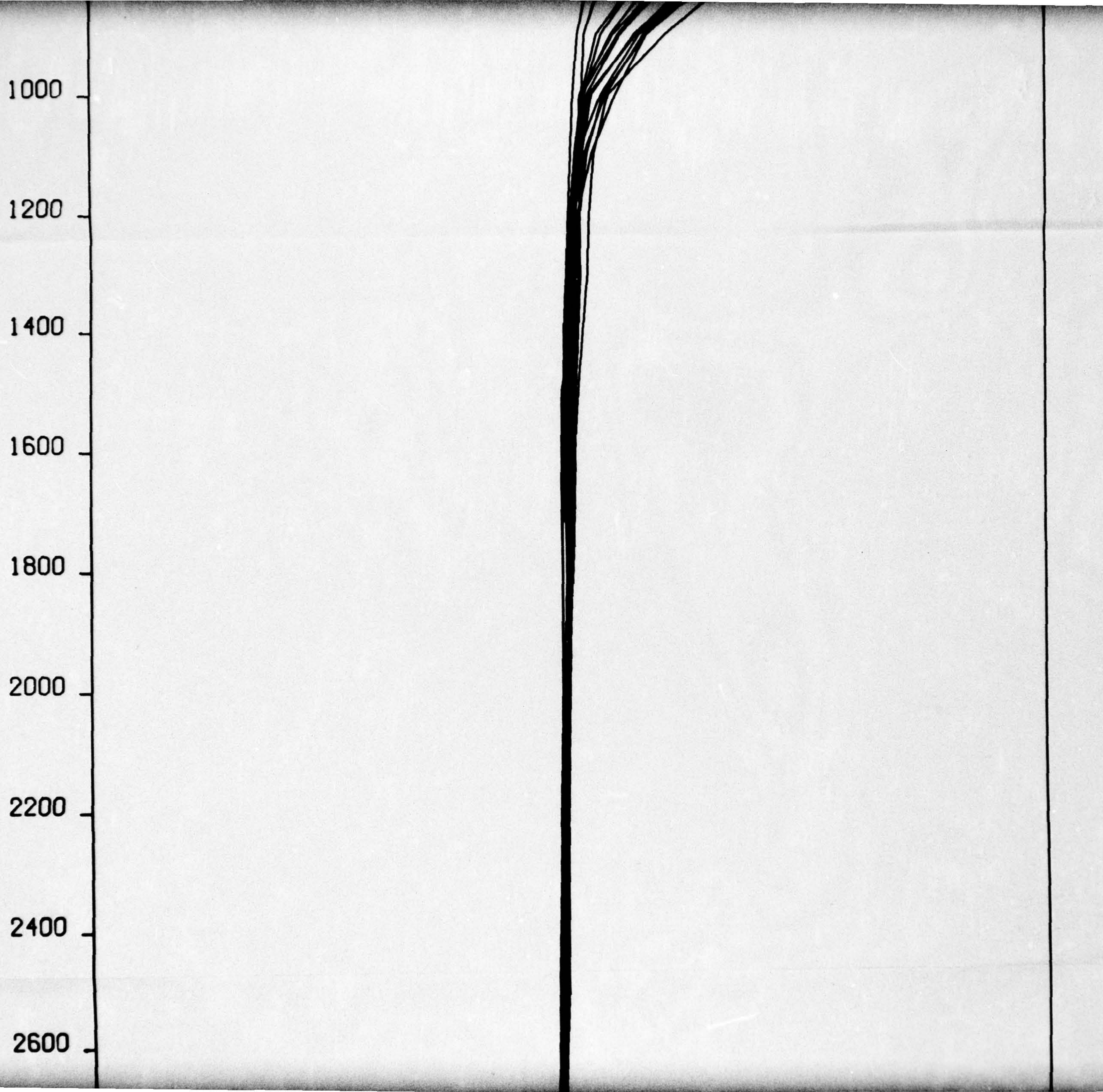
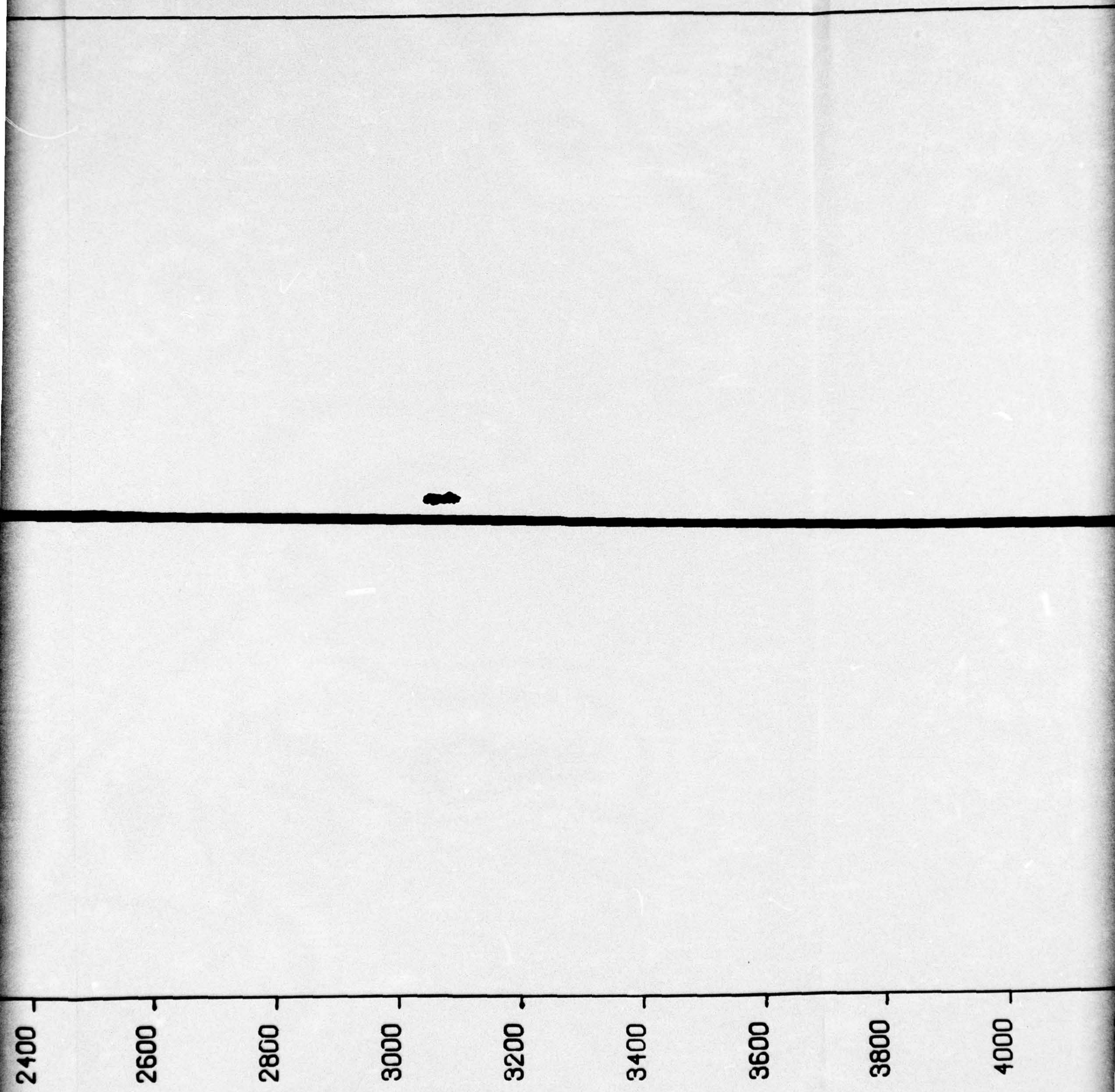


FIGURE 4 COMPOSITE OF TEMPERATURE - DEPTH

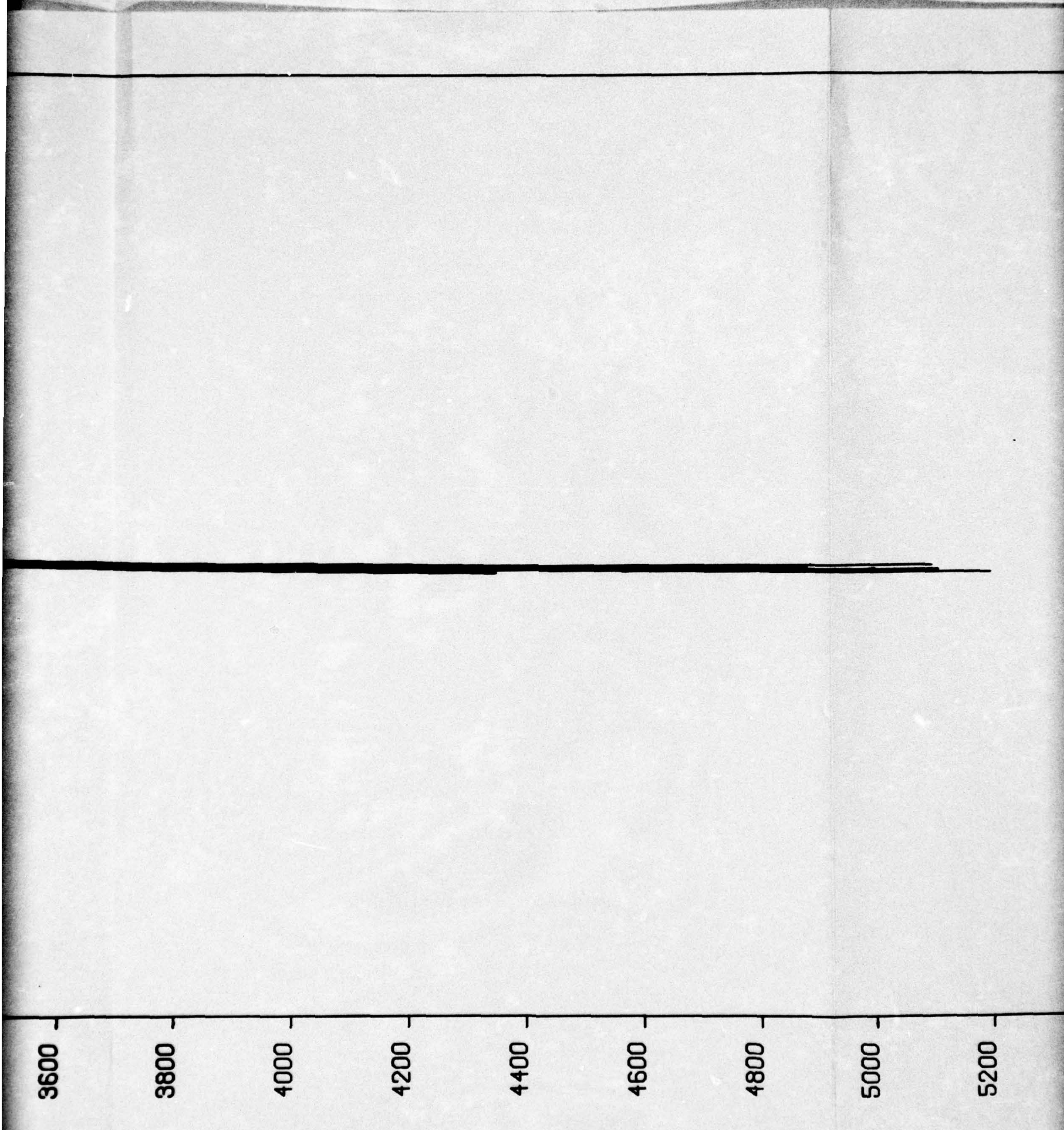

SALINITY (O/OO)
33.00
33.50
34.00
34.50
35.00
35.50
36.00
36.50
37.00
0
200
400
600
800
1000
1200
1400



2



3


3600
3800
4000
4200
4400
4600
4800
5000
5200

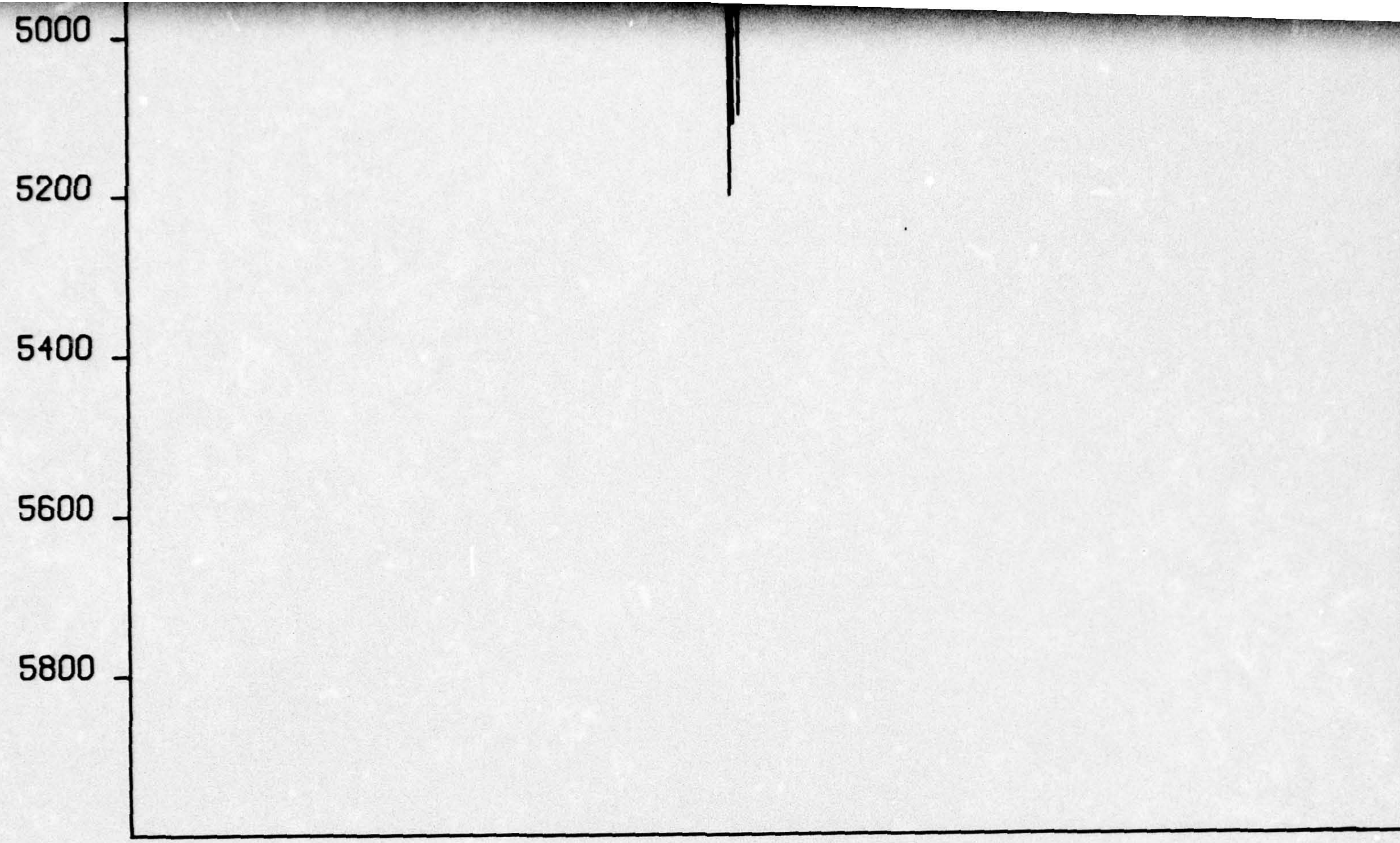


FIGURE 5 COMPOSITE OF SALINITY - DEPTH

2) There is a 36.5 $^{o}/oo$ layer which corresponds to the $18^{o}C$ water, and

3) Each salinity value in the permanent halocline varies over a depth range of about 150 meters between stations.

Variations

The two northwestern stations present some interesting features. The northwesternmost station has no $18^{o}C$ water layer and has a distinctly raised thermocline and halocline. These features make it appear to be different water compared to the Sargasso Sea, but on the temperature-salinity plot, both northwest stations fall within the composite curve of the North Atlantic Central Water. Stations similar to those found in the northwestern portion of this area could be found by sampling in the Gulf Stream. It is also possible that some process, as yet unknown, has altered the $18^{o}C$ water and raised the permanent thermocline.

Figure 6 (A through H) shows the areal distribution of temperature at selected depths. The surface shows little change, but immediately below the surface there are two distinctly high temperature areas; one on the east and one on the north side of the area. Below 200 meters, the most pronounced feature is the cold area radiating from the northwest corner.

Figure 7 (A through D) shows that the salinity contours follow closely the temperature contours. From the above it appears that a cold, low salinity gyre was located near the northwestern station at the time of the survey.

Since the eastern boundary of the Gulf Stream is indistinct, it is possible that the stream did meander enough to carry this gyre into the survey area. Furthermore, Fuglister and Worthington (1961) believe that eddies may break away from Gulf Stream meanders east of the 70th meridian and move southeastward. Such an eddy movement could have produced the observed gyre in proximity to area C_1. Finally, it is possible that pockets of cold water may be carried along on the eastern periphery of the Gulf Stream.

BATHYTHERMOGRAM ANALYSIS

Certain errors are inherent in any BT analysis. It is not easy

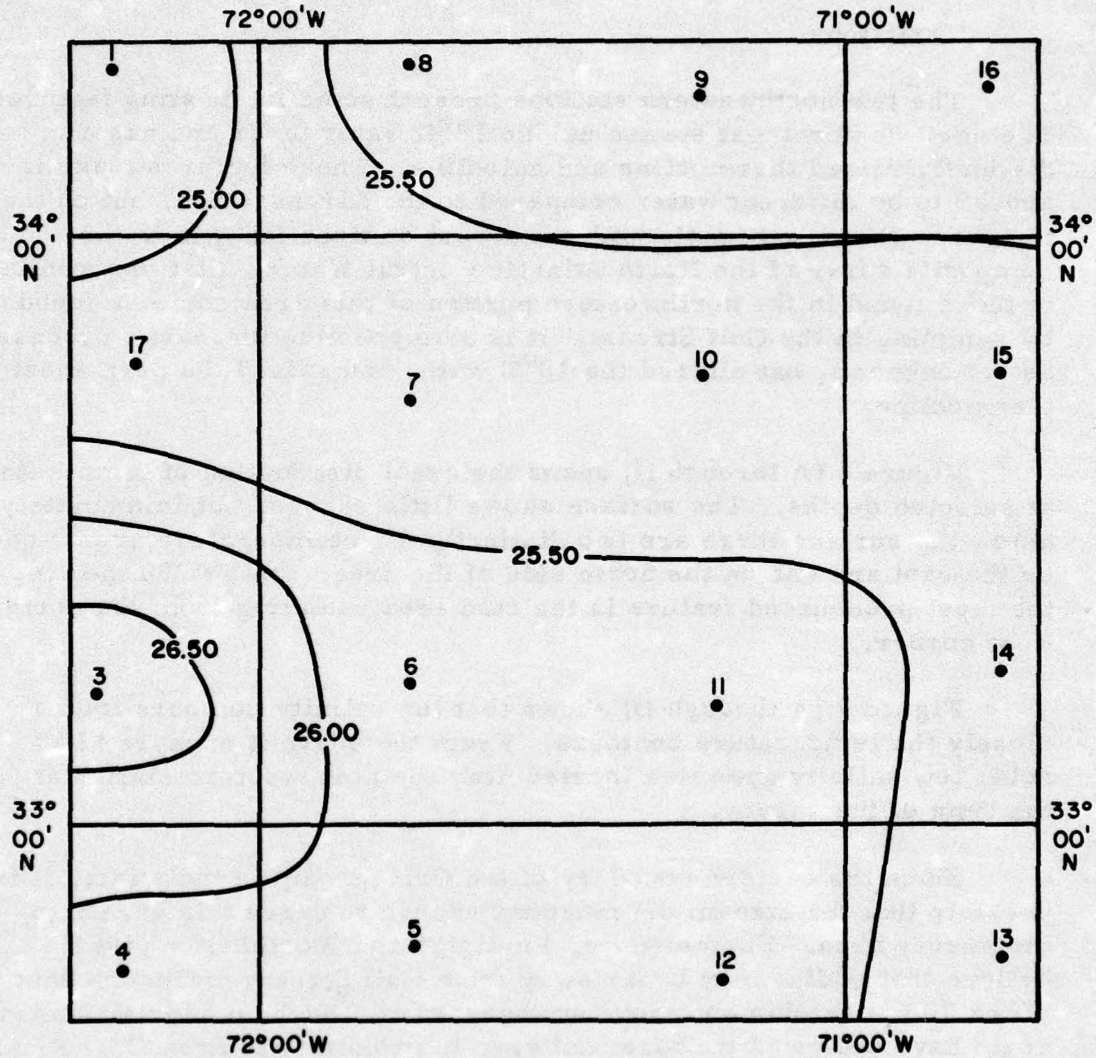


FIGURE 6a AREAL DISTRIBUTION OF TEMPERATURE AT SURFACE

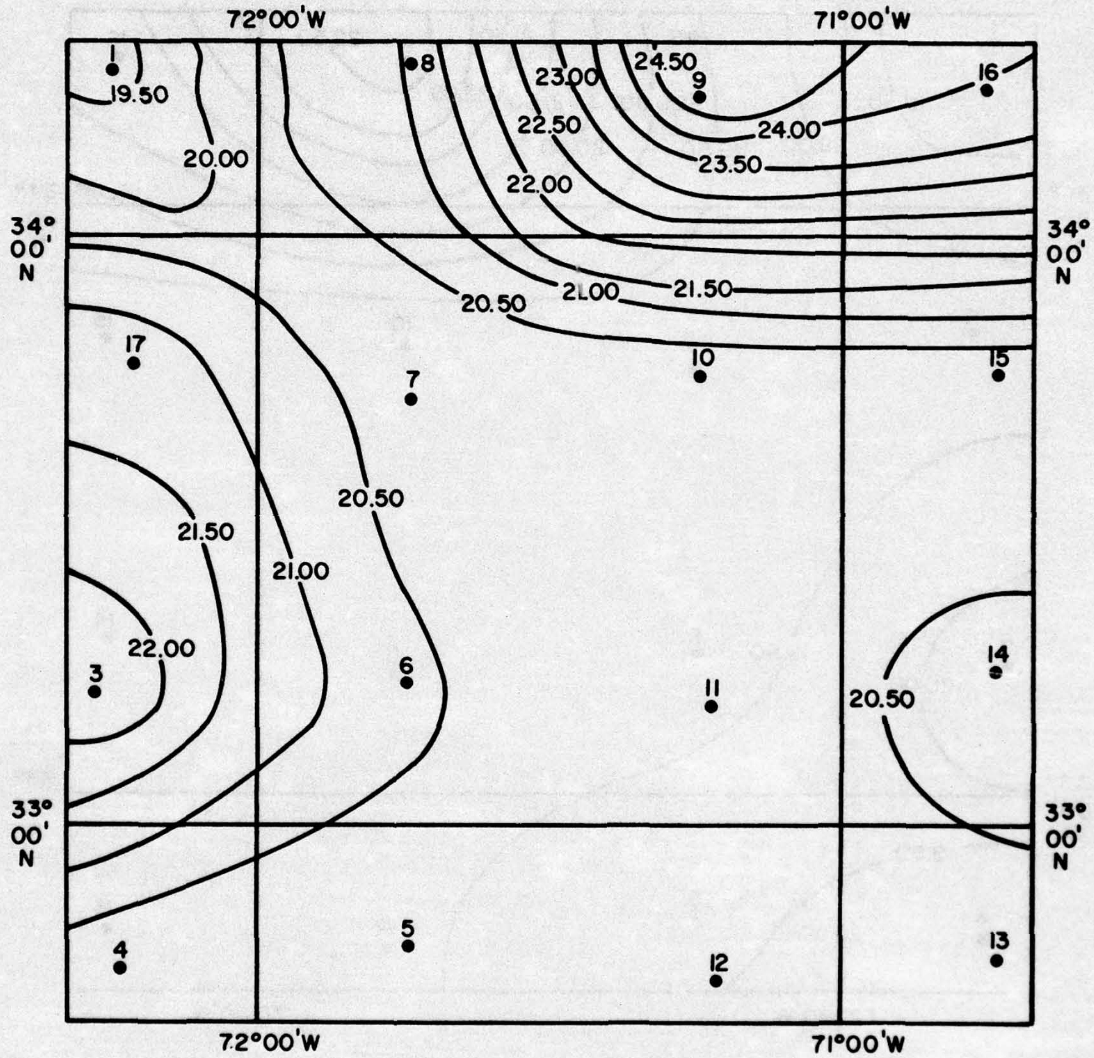


FIGURE 6b AREAL DISTRIBUTION OF TEMPERATURE AT 50 METERS

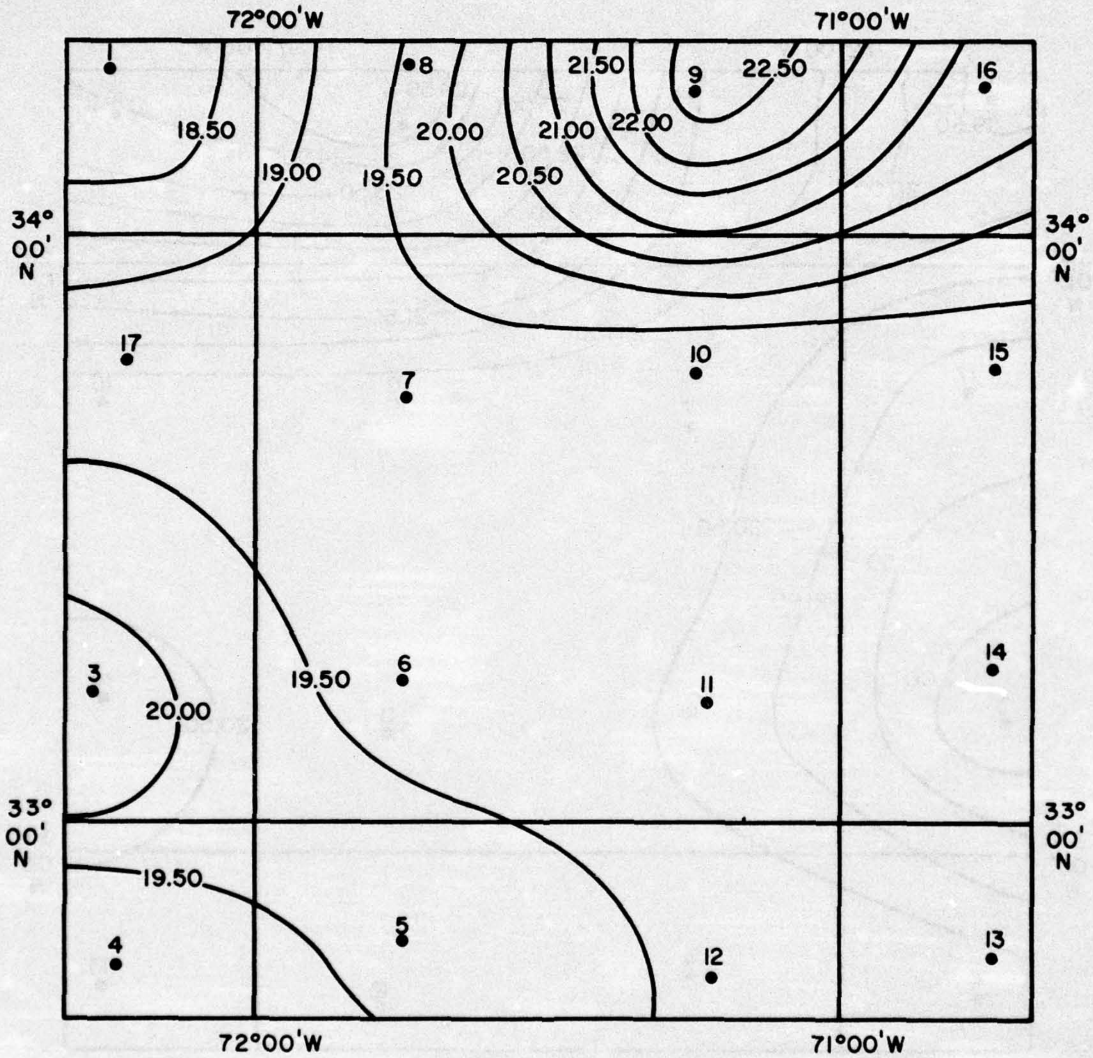


FIGURE 6c AREAL DISTRIBUTION OF TEMPERATURE AT 100 METERS

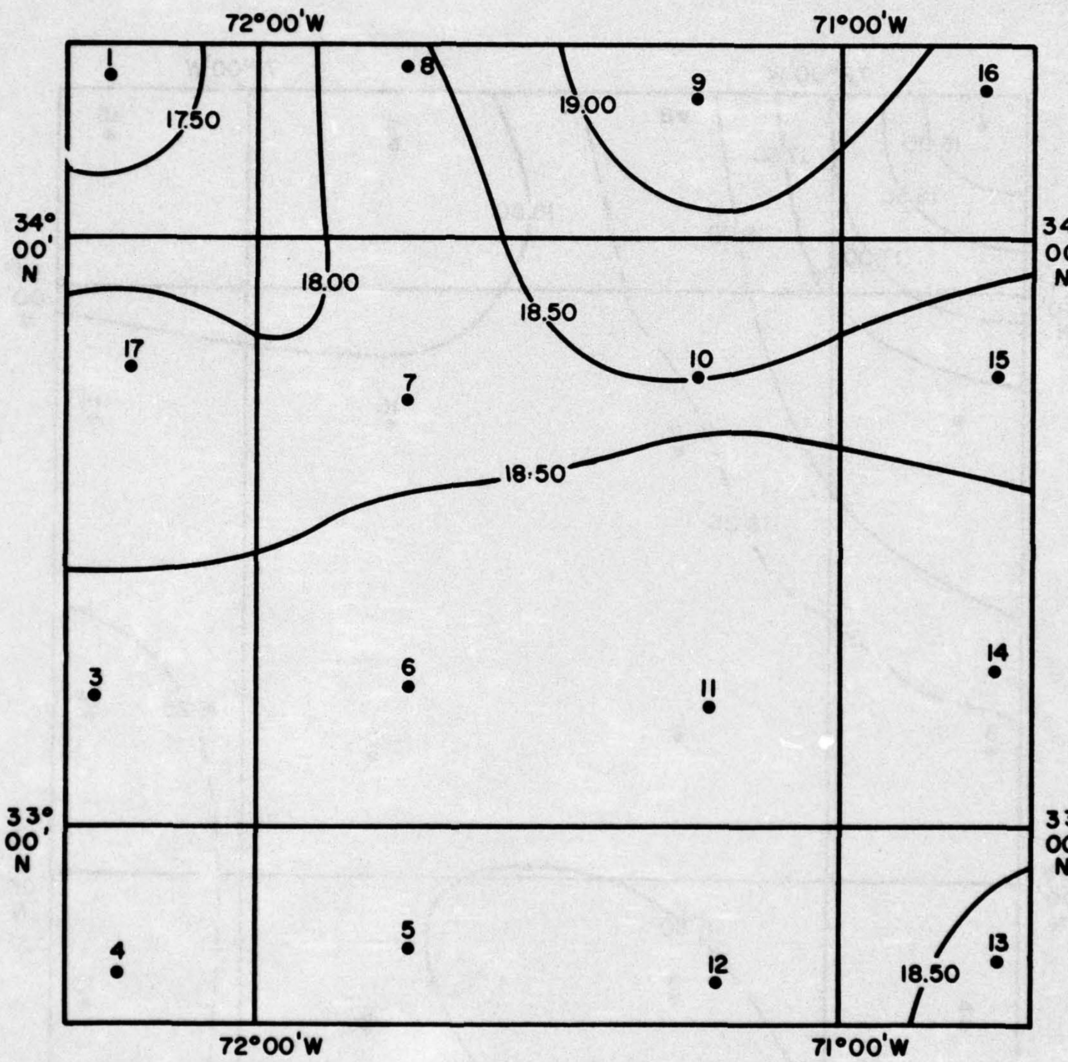


FIGURE 6d AREAL DISTRIBUTION OF TEMPERATURE AT 200 METERS

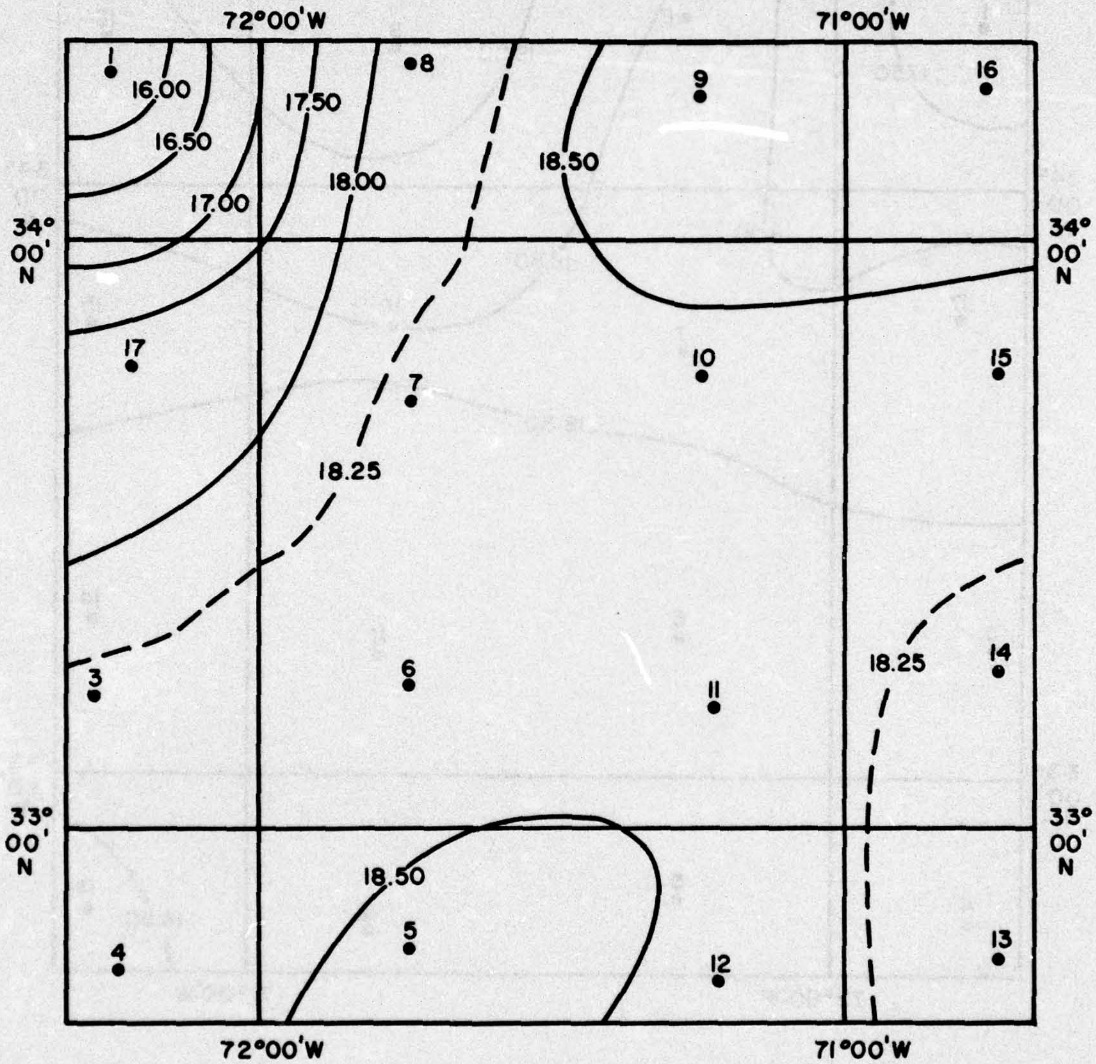


FIGURE 6e AREAL DISTRIBUTION OF TEMPERATURE AT 300 METERS

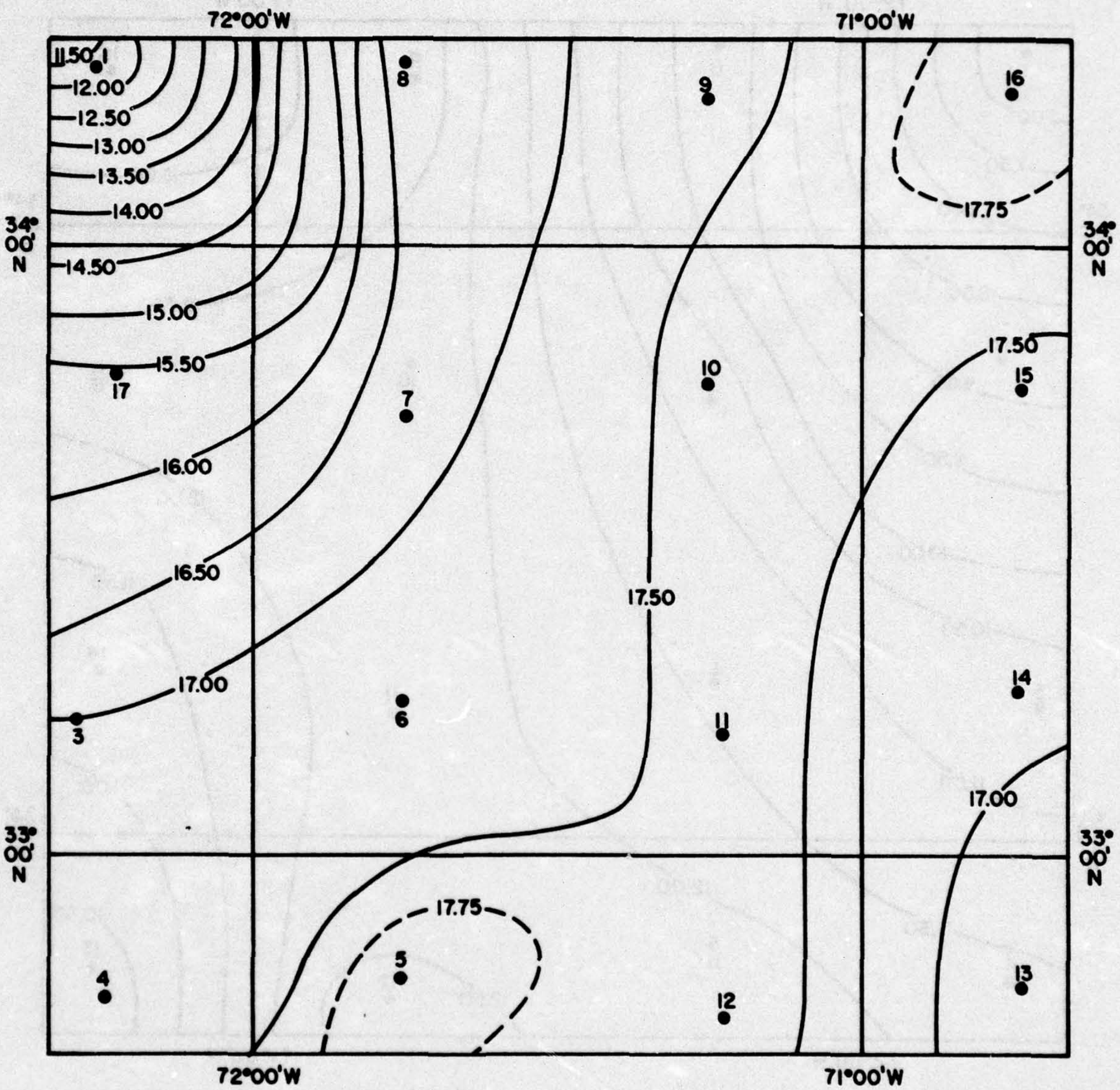


FIGURE 6f AREAL DISTRIBUTION OF TEMPERATURE AT 500 METERS

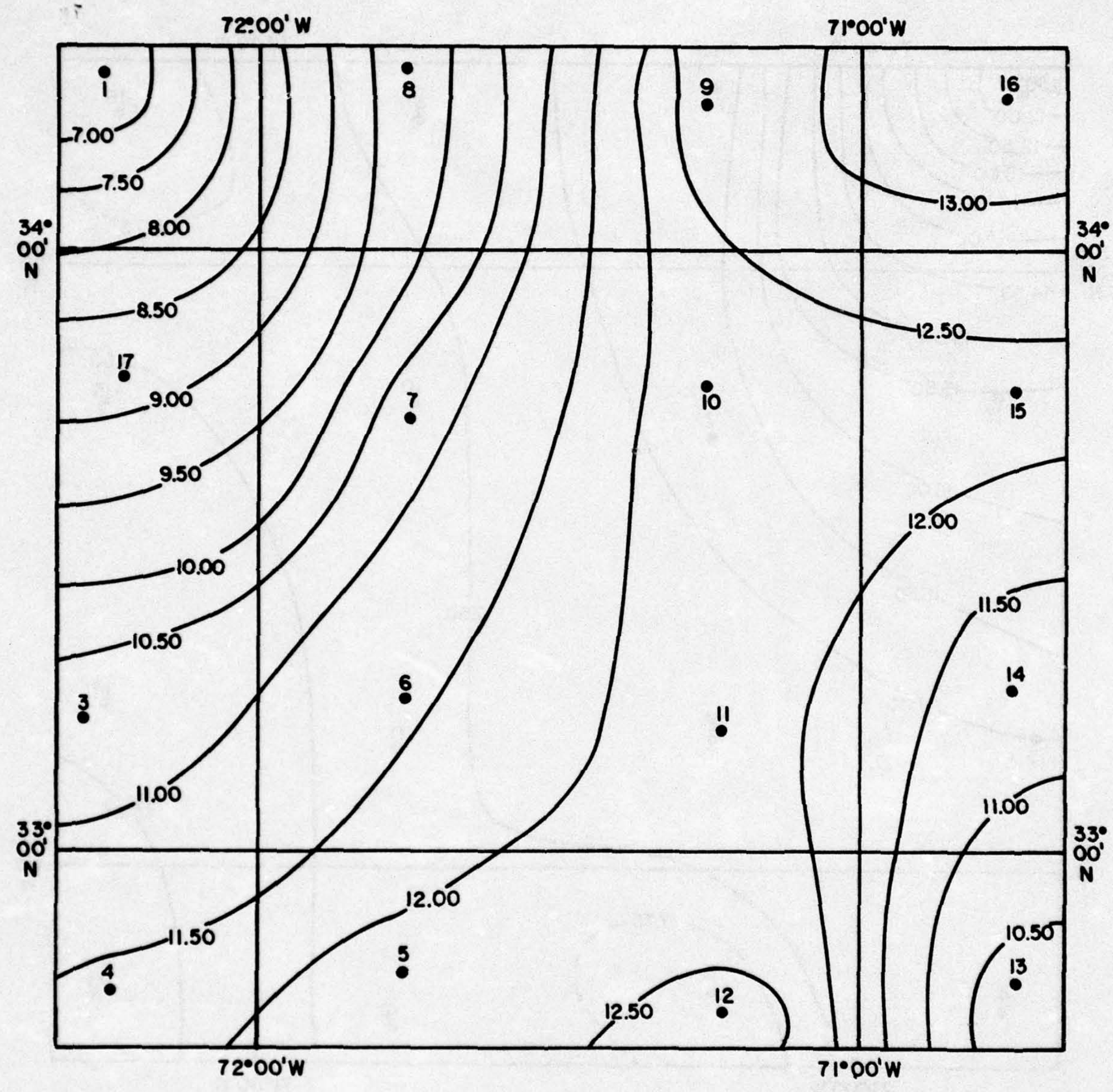


FIGURE 6g AREAL DISTRIBUTION OF TEMPERATURE AT 800 METERS

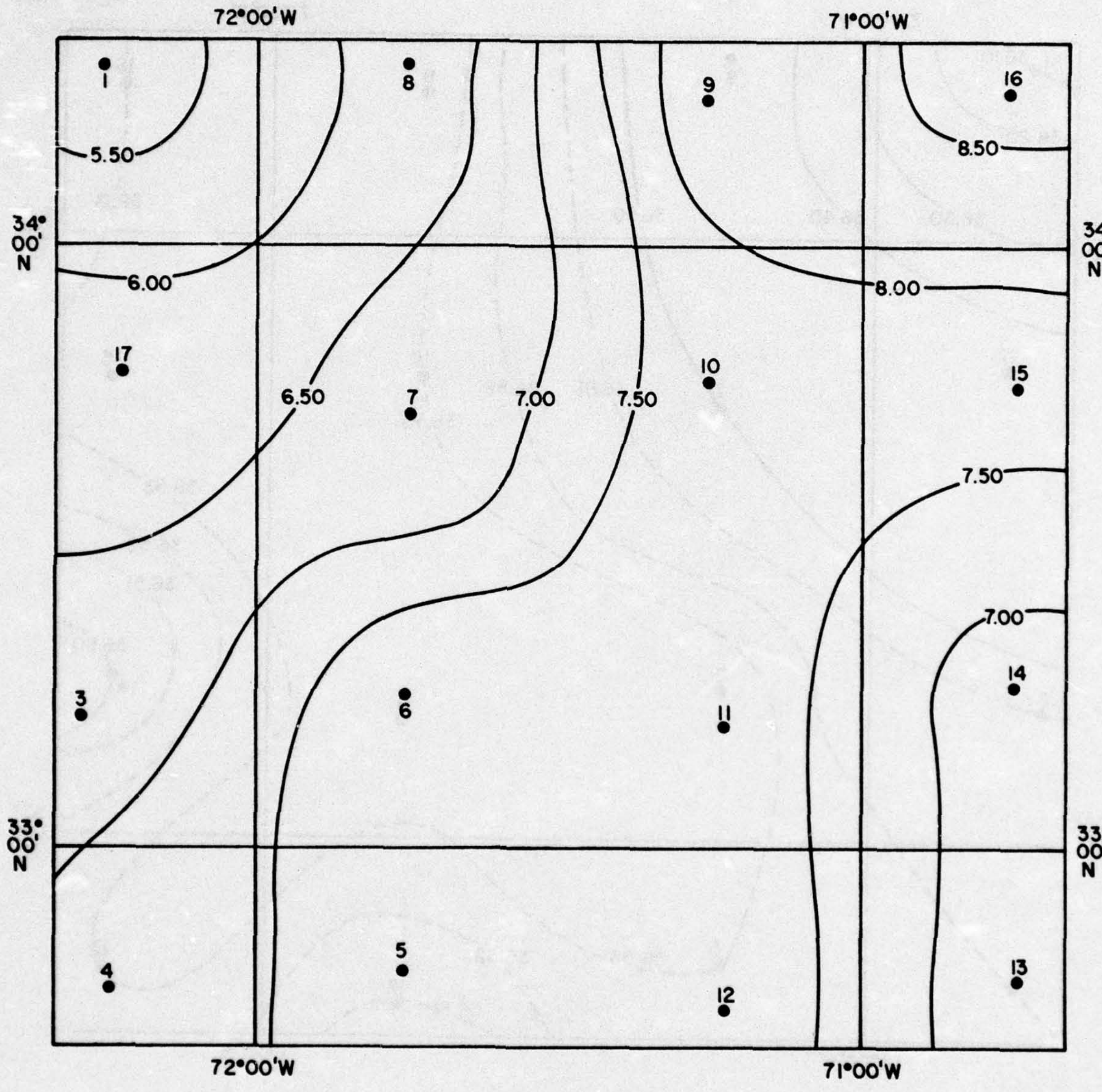


FIGURE 6h AREAL DISTRIBUTION OF TEMPERATURE AT 1000 METERS

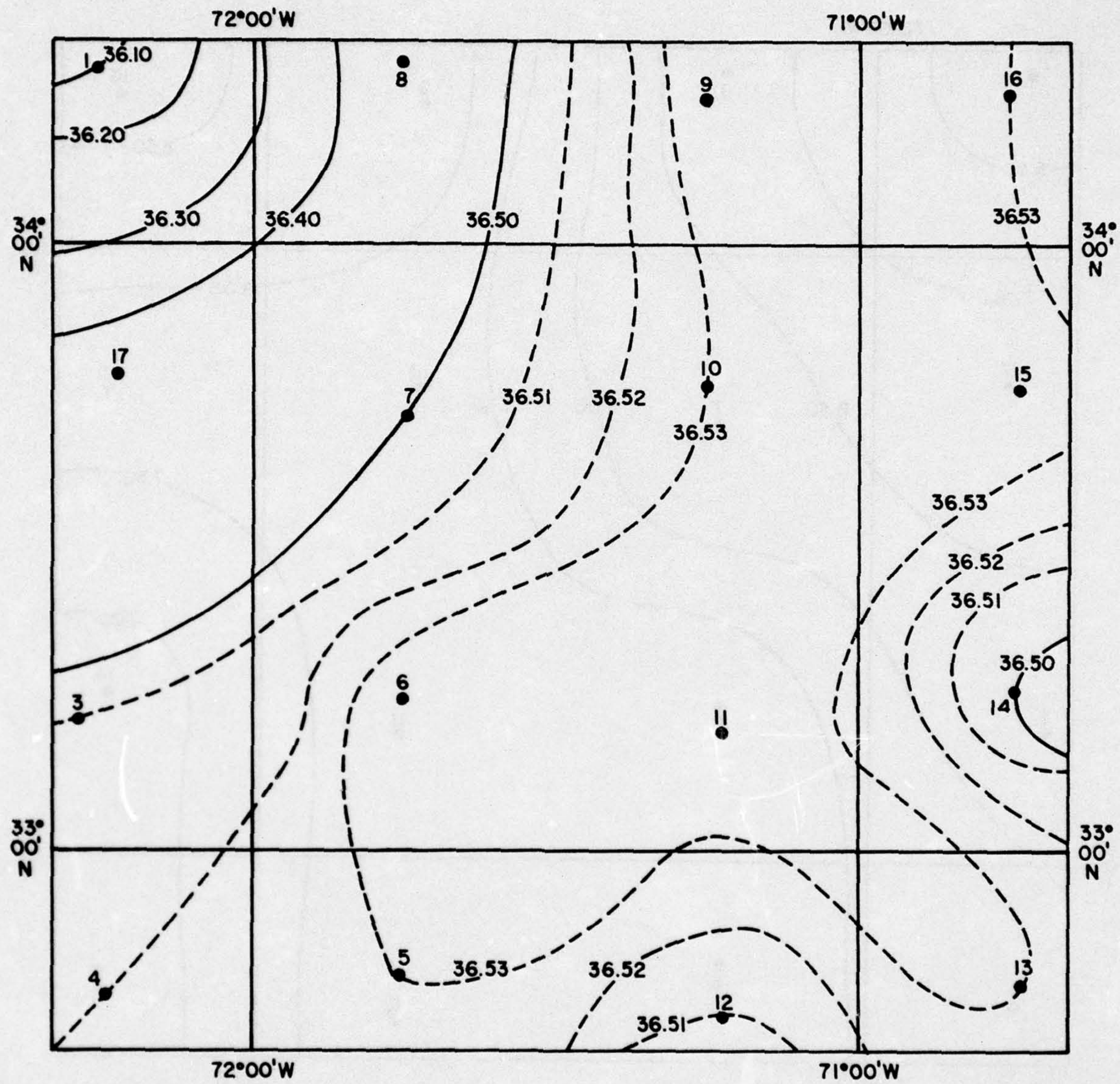


FIGURE 7a AREAL DISTRIBUTION OF SALINITY AT 300 METERS

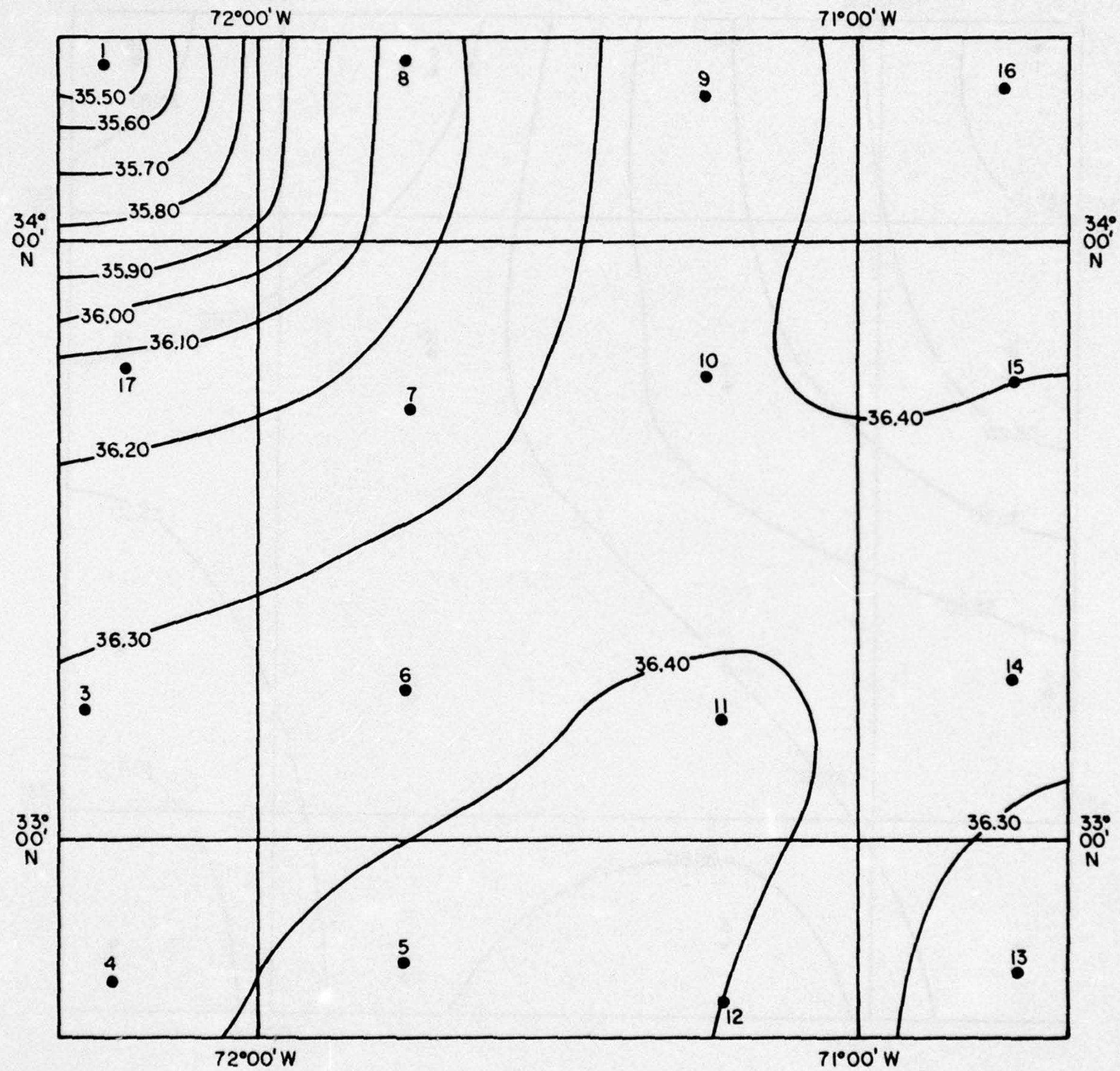


FIGURE 7b AREAL DISTRIBUTION OF SALINITY AT 500 METERS

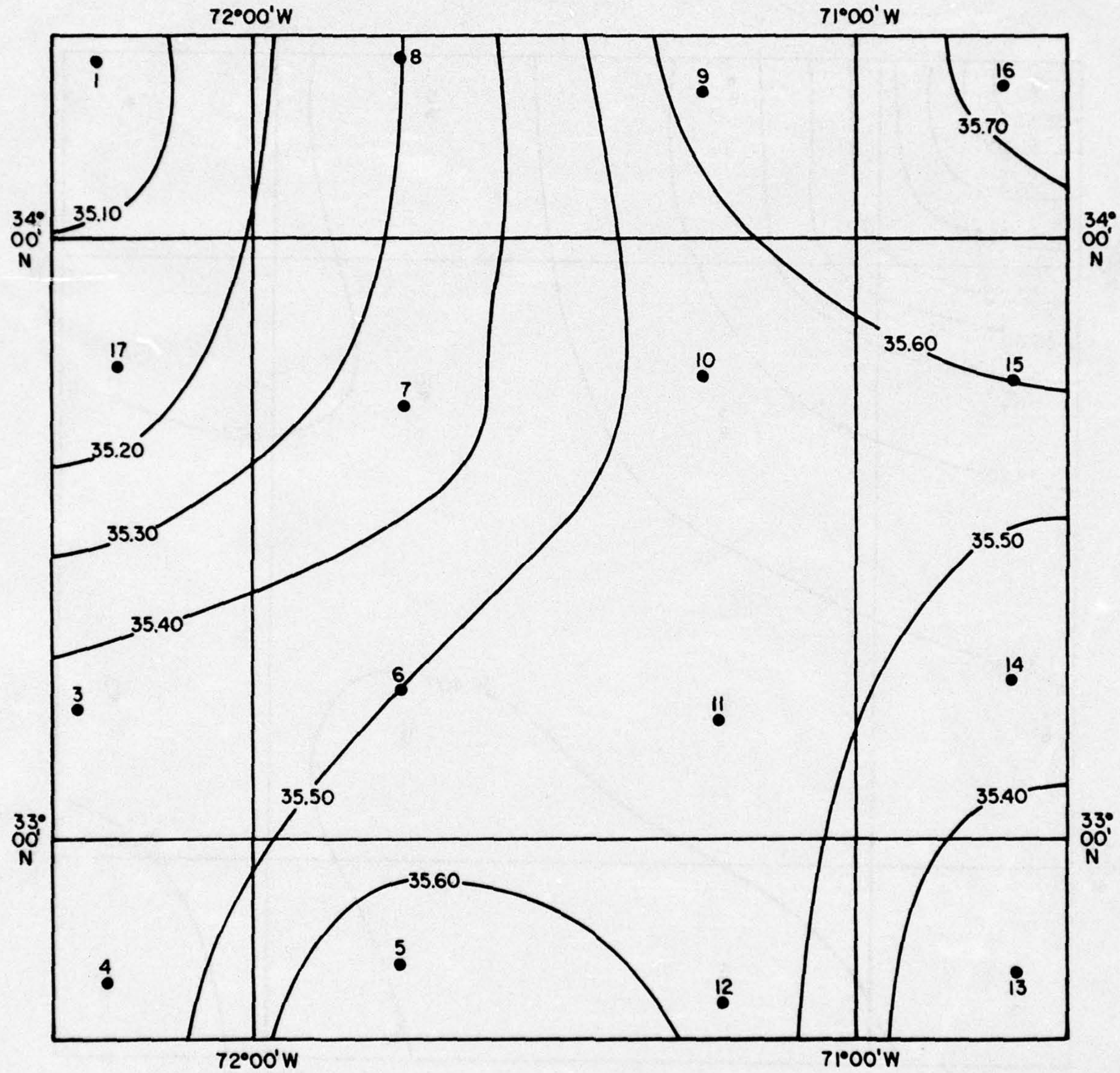


FIGURE 7c AREAL DISTRIBUTION OF SALINITY AT 800 METERS

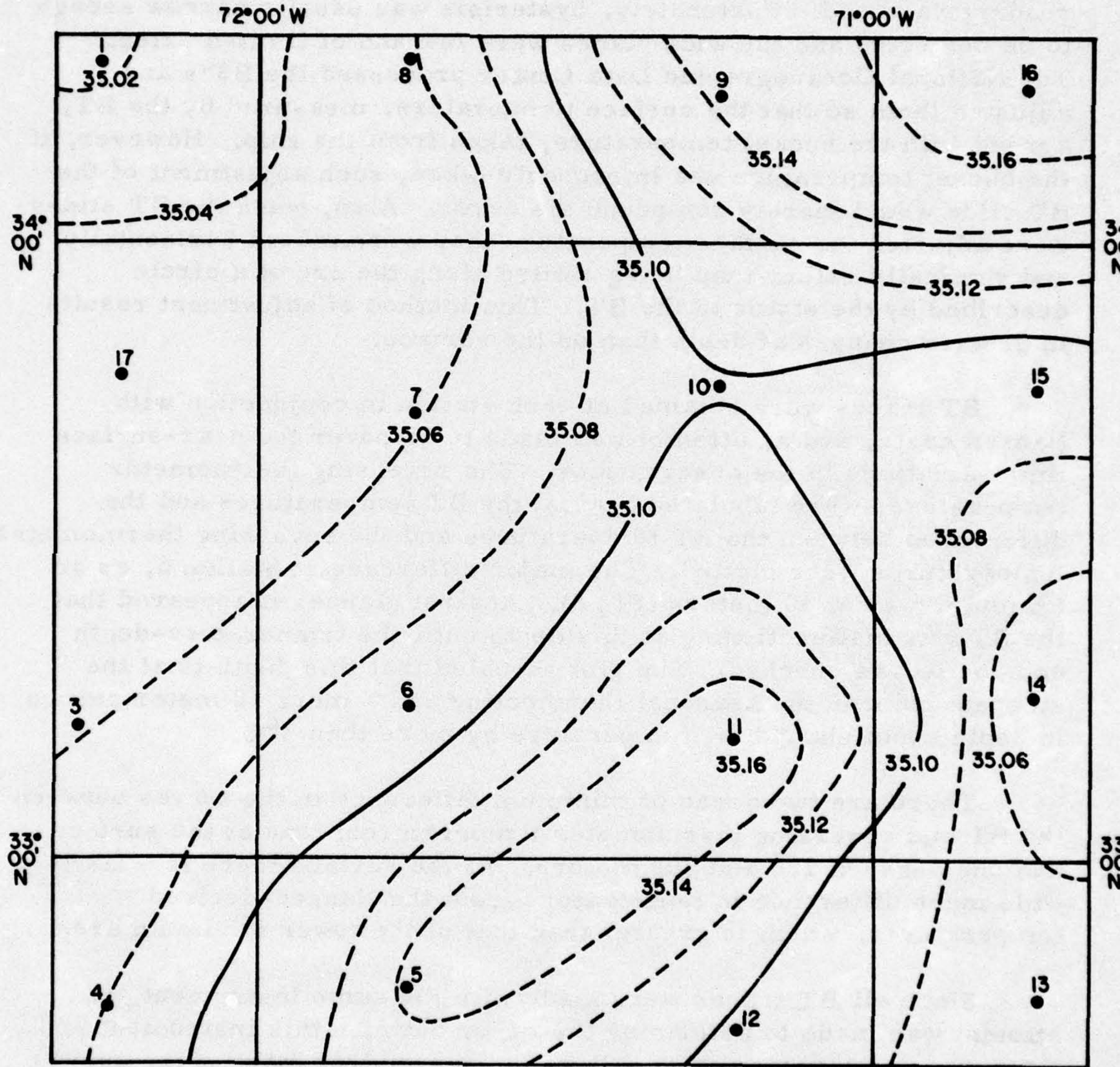


FIGURE 7d AREAL DISTRIBUTION OF SALINITY AT 1000 METERS

to read the BT trace to tenths of a degree; however, to minimize this error in analysis, the right edge of the trace was used, which gives fairly good results. If there was hysterisis in a trace, the highest reading was used. Fortunately, hysterisis was usually narrow enough to be neglected and the wide places were few and of limited extent. The National Oceanographic Data Center processed the BT's and adjusted them so that the surface temperature, measured by the BT, agreed with the bucket temperature, taken from the ship. However, if the bucket temperature was improperly taken, such adjustment of the BT slide would merely compound the error. Also, when the BT slides were adjusted for surface temperature they were moved horizontally and vertically rather than being shifted along the arc of a circle described by the stylus of the BT. This method of adjustment results in greater changes at depth than on the surface.

BT traces were obtained at each station in conjunction with Nansen casts, and an attempt was made to discover the near-surface time variations in the observations. The reversing thermometer temperatures were tabulated against the BT temperatures and the differences between the BT temperatures and the reversing thermometer temperatures were plotted. The major difference at Station 6, as an example, was at 30 meters (Fig 8). At first glance, it appeared that the BT was malfunctioning at this depth until the temperature-depth composite was checked. The plot revealed that this depth is at the steepest point in the seasonal thermocline and a mere 10 meter change in depth could change the temperature by more than 2°C.

There are two areas of minimum difference in the curves between the BT and reversing thermometer temperatures: one at the surface and one between 150 and 200 meters. At the surface there is a fairly wide mean difference in temperature from the Nansen-derived temperatures, which is greater than that of the lower minimum area.

Since all BT traces were made with the same instrument, an attempt was made to determine the error between this instrument and the reversing thermometers. It was observed that most of the curves of difference between BT traces and reversing thermometers had more negative than positive differences, so a mean of all the BT temperatures between 150 and 200 meters was taken. A mean deviation of -0.3°C resulted which was taken as the most probable calibration factor for the BT relative to the reversing thermometers. It may be noted that at 150 meters the mean difference was -0.4°C, while at 200 meters the

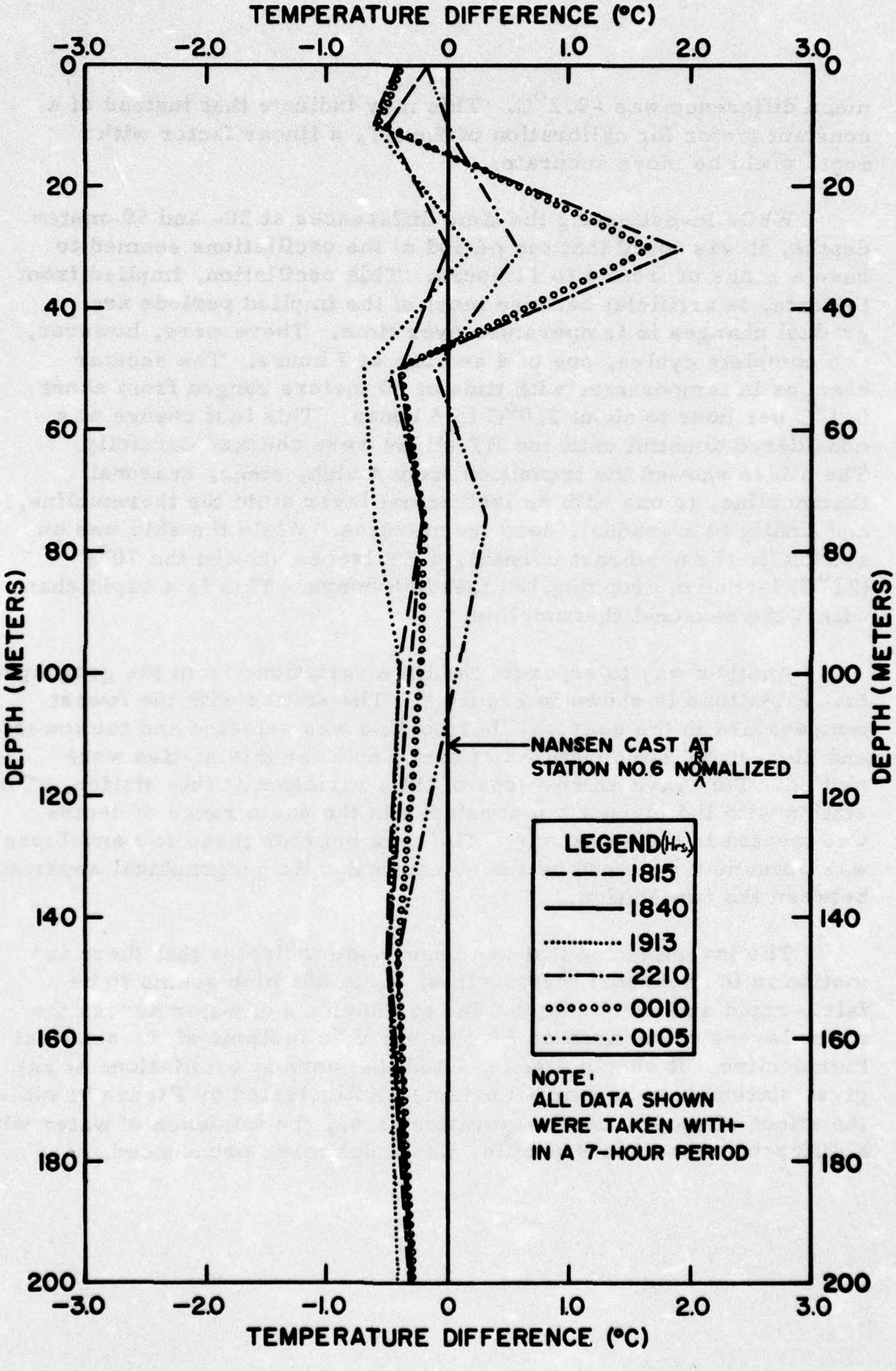


FIGURE 8 DIFFERENCE BETWEEN BTs AND REVERSING THERMOMETERS

mean difference was $-0.2^{\circ}C$. This may indicate that instead of a constant factor for calibration of the BT, a linear factor with depth would be more accurate.

While investigating the time differences at 30- and 50-meter depths, it was found that the period of the oscillations seemed to have a range of from 4 to 11 hours. This oscillation, implied from the data, is artificial because most of the implied periods are gradual changes in temperature over time. There were, however, two complete cycles, one of 4 and one of 7 hours. The secular changes in temperature with time at 30 meters ranged from about $0.1^{\circ}C$ per hour to about $3.0^{\circ}C$ in 5 hours. This last change was considered doubtful until the BT slides were checked carefully. The slides showed the transition from a high, steep, seasonal thermocline, to one with an isothermal layer amid the thermocline, and finally to a gradual, deep thermocline. While the ship was on station (in the northeast corner), 4 BT traces showed the $70^{\circ}F$ ($21^{\circ}C$) isotherm dropping 100 feet in 8 hours. This is a rapid change within the seasonal thermocline.

Another way to separate the time variations from the geographical variations is shown in Figure 9. The station with the lowest temperature in the seasonal thermocline was selected and the lowest and highest BT temperatures at each depth for this station were plotted. This gave an envelope of time variation at this station. The station with the highest temperatures in the same range of depths was treated in the same way. The area between these two envelopes was presumably caused by the 60 nautical mile geographical separation between the two stations.

The investigation that has been made indicates that there is motion in the seasonal thermocline, some of which seems to be fairly rapid and which may be due to movement of water across the upper layers of the area or may be periodic motions of the seasonal thermocline. It should also be noted that normal oscillations at any given station were of limited extent, as illustrated by Figure 9; while the effect of geographical separation, i.e., the influence of water with a different temperature profile, was much more pronounced.

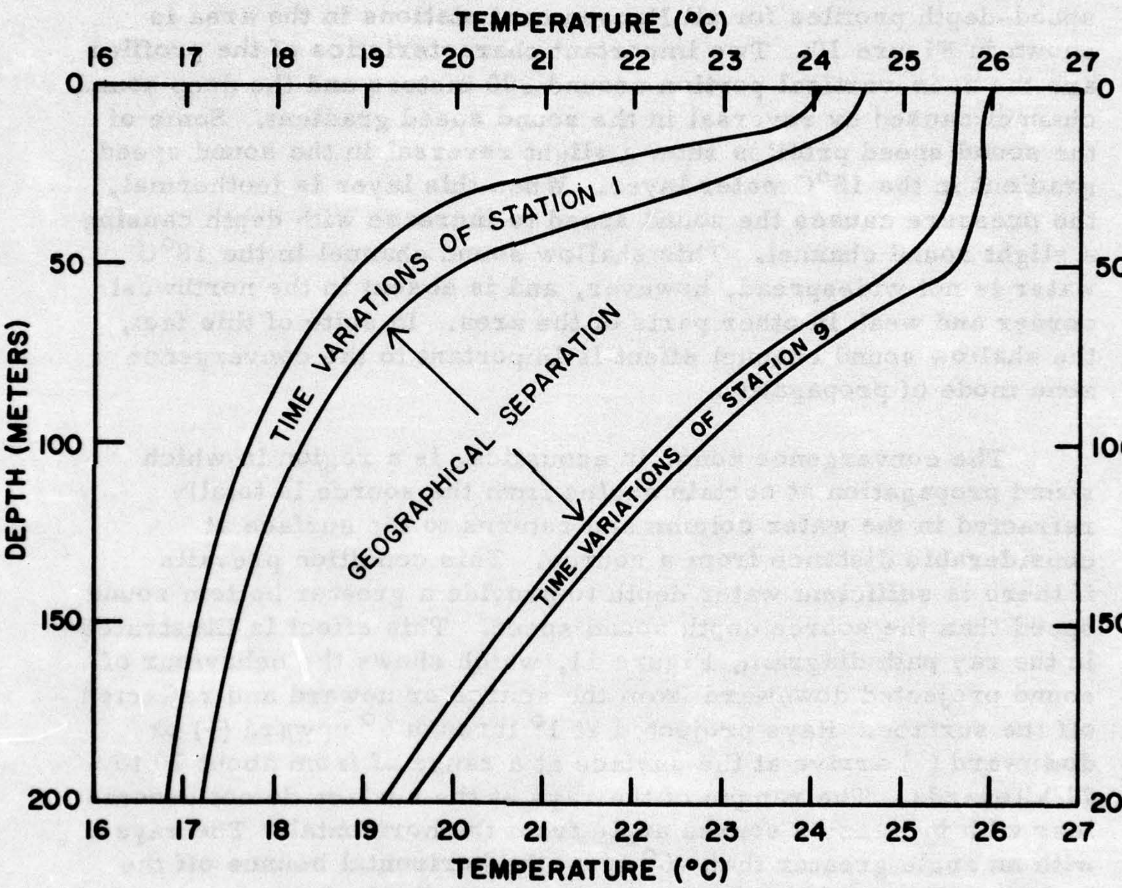


FIGURE 9 TEMPERATURE-DEPTH SHOWING TIME AS A FUNCTION OF GEOGRAPHICAL LOCATION

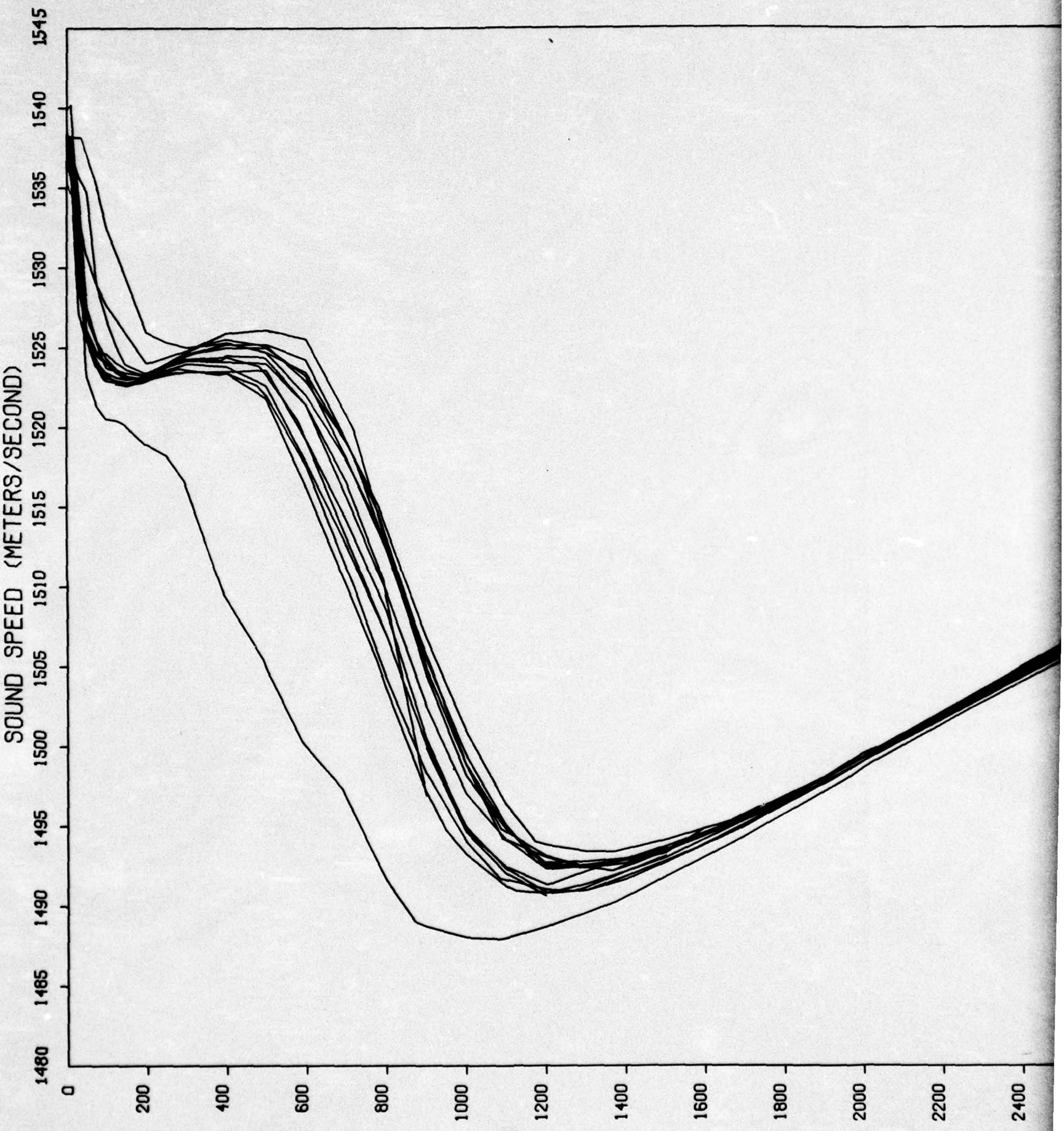
ACOUSTICS

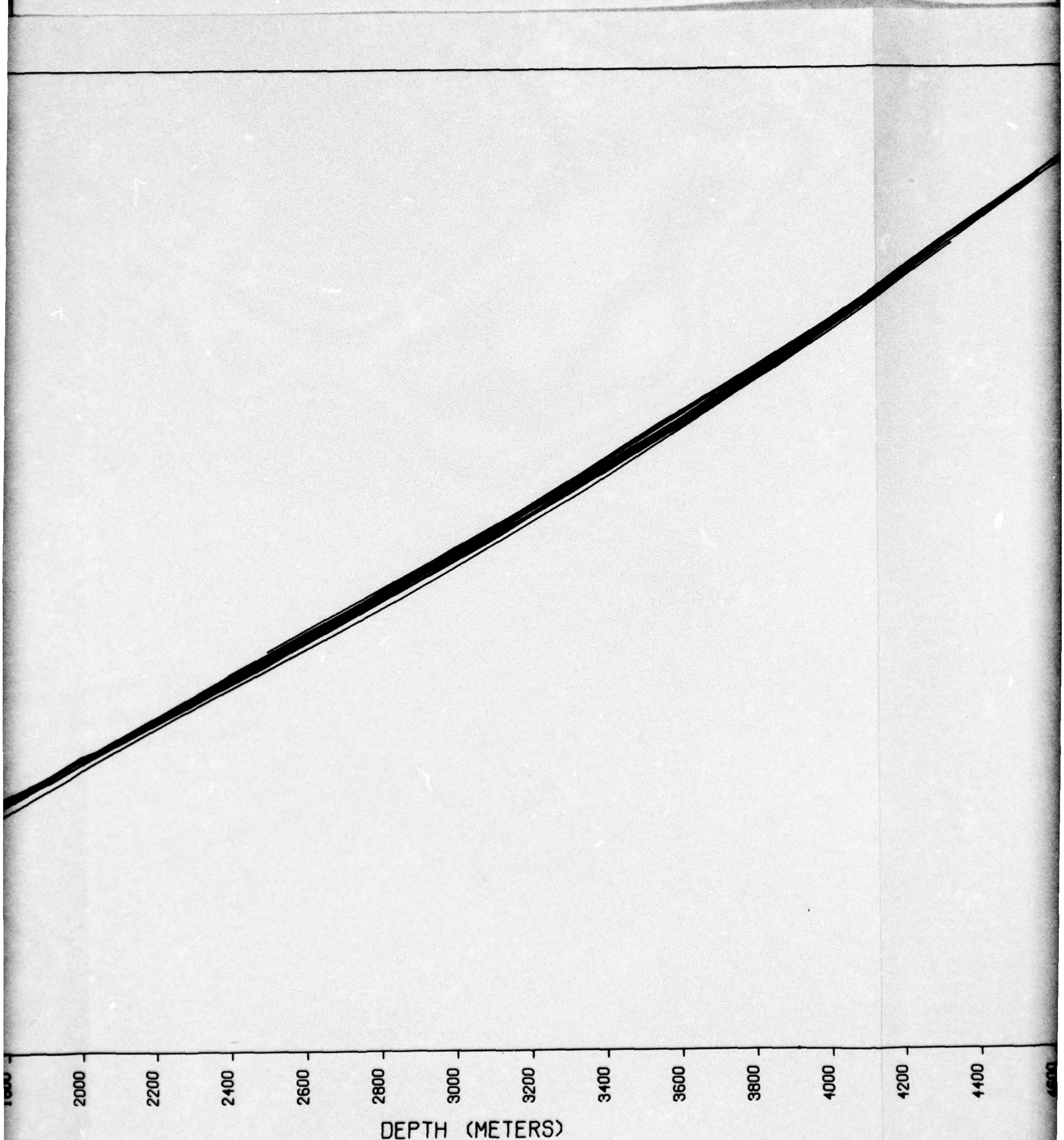
Sound Speed Profiles

Though similar to the temperature profiles, the smoothed sound speed profiles have distinct features. A composite of sound speed-depth profiles for all Nansen cast stations in the area is shown in Figure 10. Two important characteristics of the profiles are the near-vertical portion around 300 meters and the deep sound channel caused by reversal in the sound speed gradient. Some of the sound speed profiles show a slight reversal in the sound speed gradient in the 18°C water layer. When this layer is isothermal, the pressure causes the sound speed to increase with depth causing a slight sound channel. This shallow sound channel in the 18°C water is not widespread, however, and is absent in the northwest corner and weak in other parts of the area. In spite of this fact, the shallow sound channel effect is important to the convergence zone mode of propagation.

The convergence zone, in acoustics, is a region in which sound propagation at certain angles from the source is totally refracted in the water column and returns to the surface at considerable distance from a source. This condition prevails if there is sufficient water depth to provide a greater bottom sound speed than the source depth sound speed. This effect is illustrated in the ray path diagram, Figure 11, which shows the behaviour of sound projected downward from the source or upward and reflected off the surface. Rays projected at 1° through 6° upward (+) or downward (-) arrive at the surface at a range of from about 70 to 71 kiloyards. The ranges of the rays at the surface do not become less with increasing source angle from the horizontal. The rays with an angle greater than -6° from the horizontal bounce off the bottom. These bottom bounce rays are angularly dependent, or in other words, increasing angle causes decreasing range.

This figure also illustrates the effect that a horizontal change in the water column can have on convergence zone propagation. The two profiles, illustrated on the left of the figure, were located 62 kiloyards apart. The ray path was computed using both profiles, with a change of profile at 31 kiloyards. The shaded area in the convergence zone illustrates the arrival pattern based on Station 3 alone; the minimum range was about 1000 yards greater and the convergence zone was wider. This is not a great change, but evidence


SOUND SPEED (METERS/SECOND)
1480
1485
1490
1495
1500
1505
1510
1515
1520
1525
1530
1535
1540
1545
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400



2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
DEPTH (METERS)

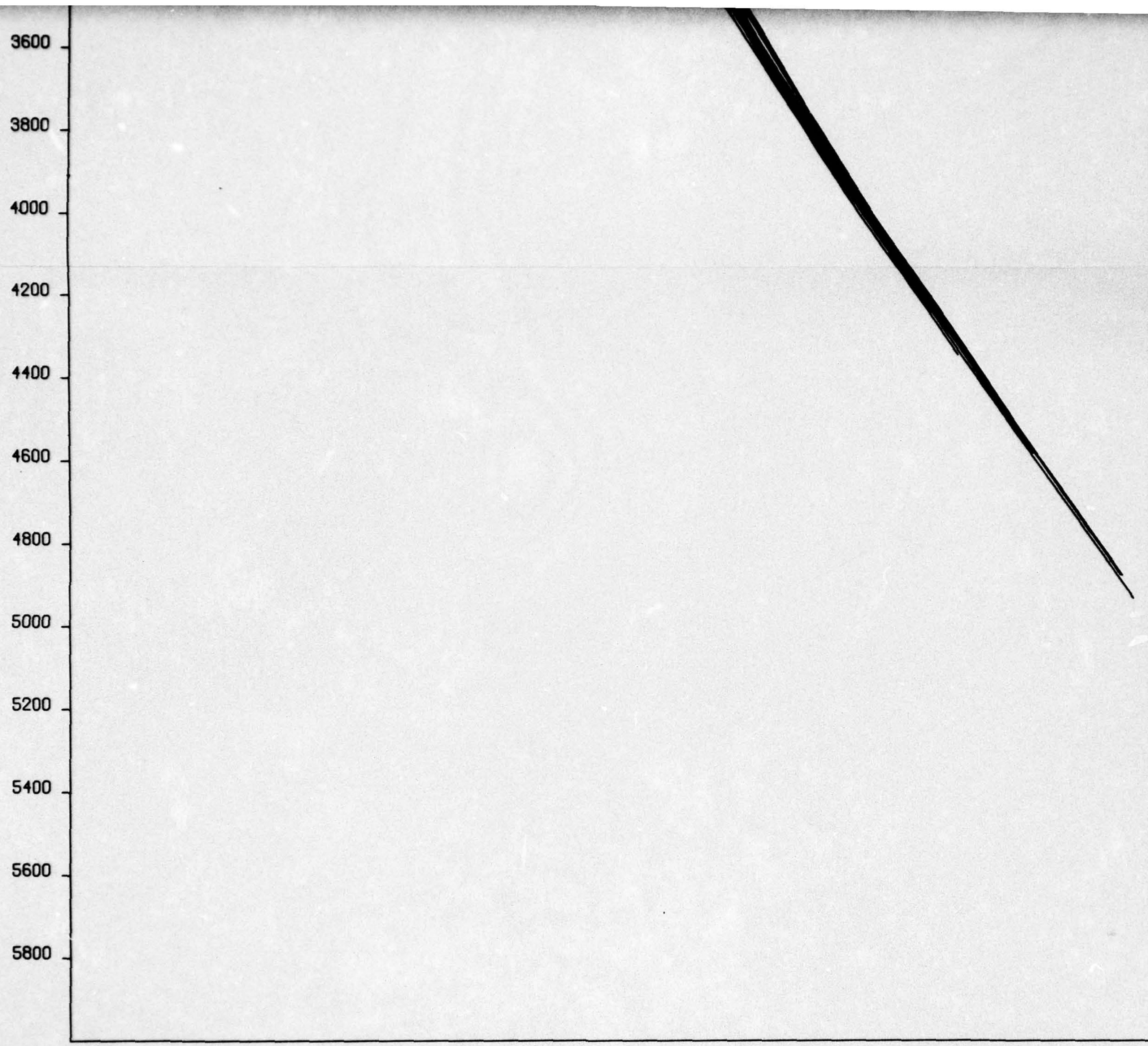
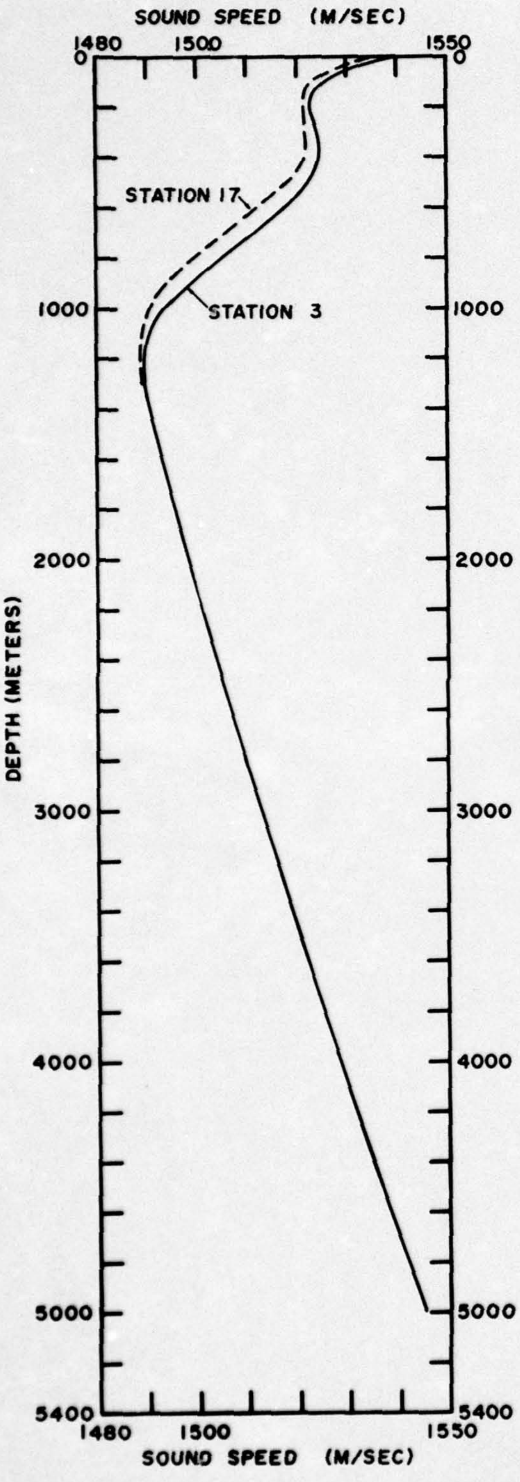
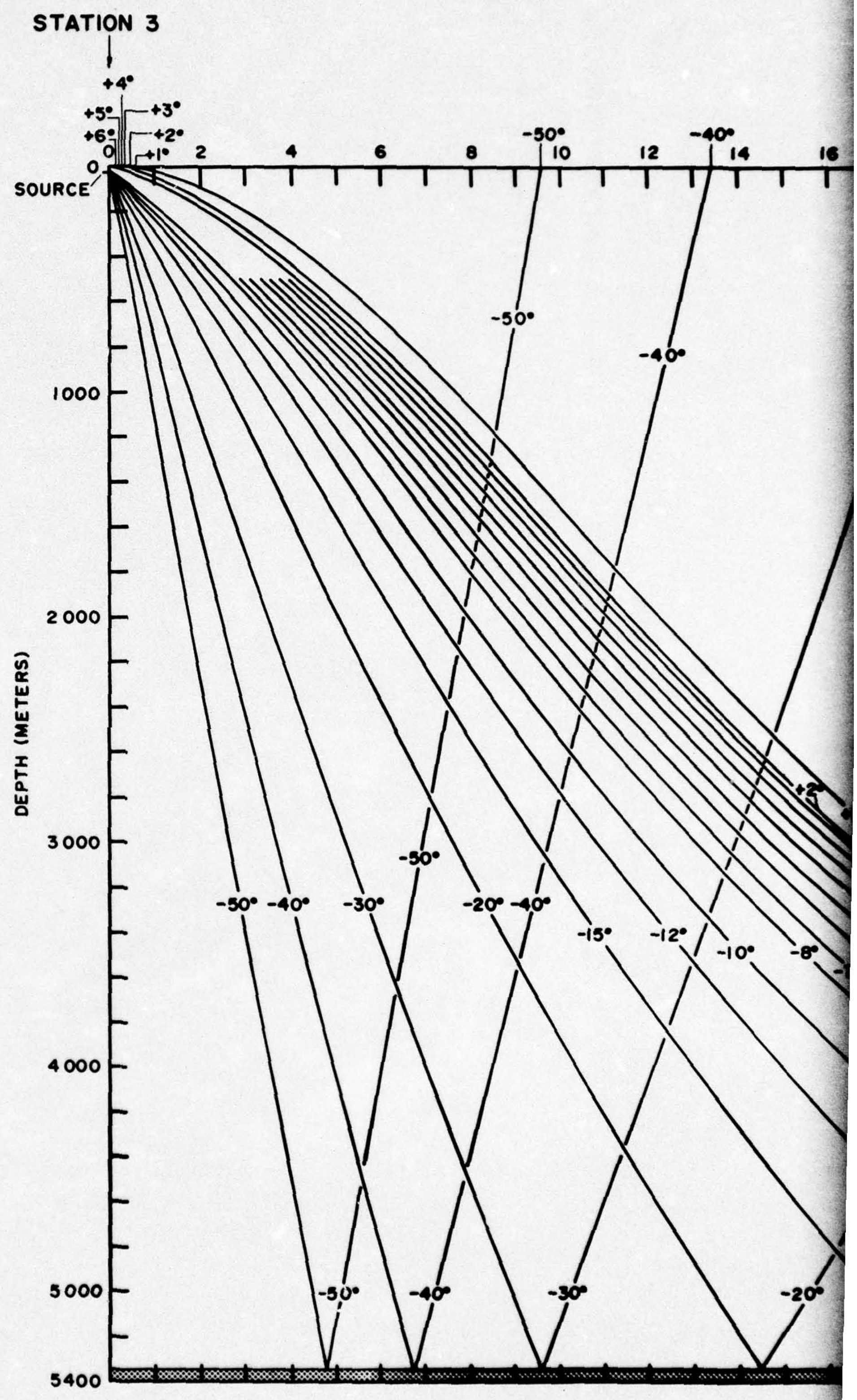


FIGURE 10 COMPOSITE OF SOUND SPEED - DEPTH

3


SOUND SPEED (M/SEC)
1480
1500
1550
0
1000
2000
3000
4000
5000
5400
DEPTH (METERS)
STATION 17
STATION 3


STATION 3
+4°
+5°
+3°
+6°
+2°
+1°
SOURCE
0
2
4
6
8
10
12
14
16
-50°
-40°
-30°
-20°
-15°
-12°
-10°
-8°
+2°
1000
2000
3000
4000
5000
5400
DEPTH (METERS)

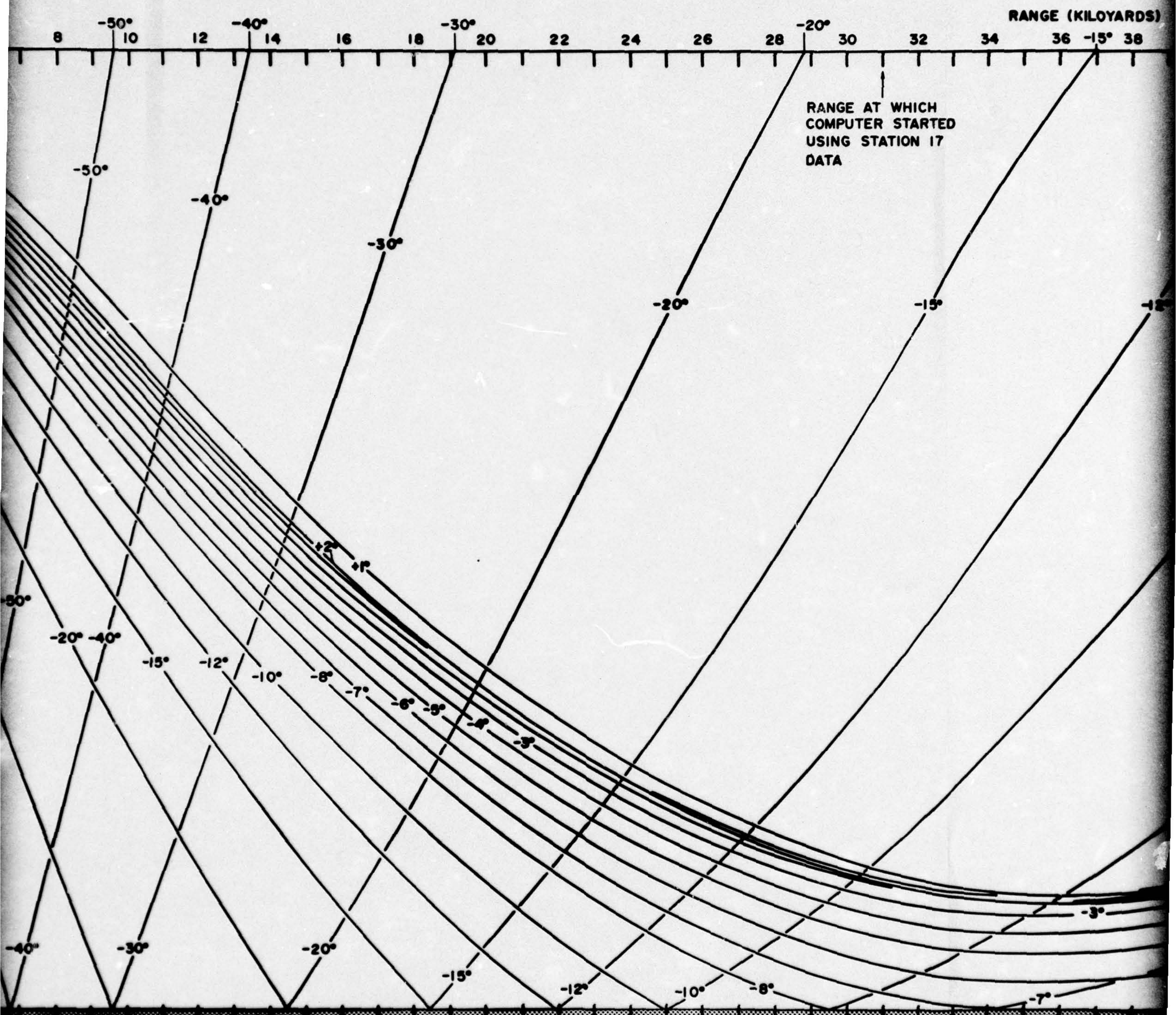
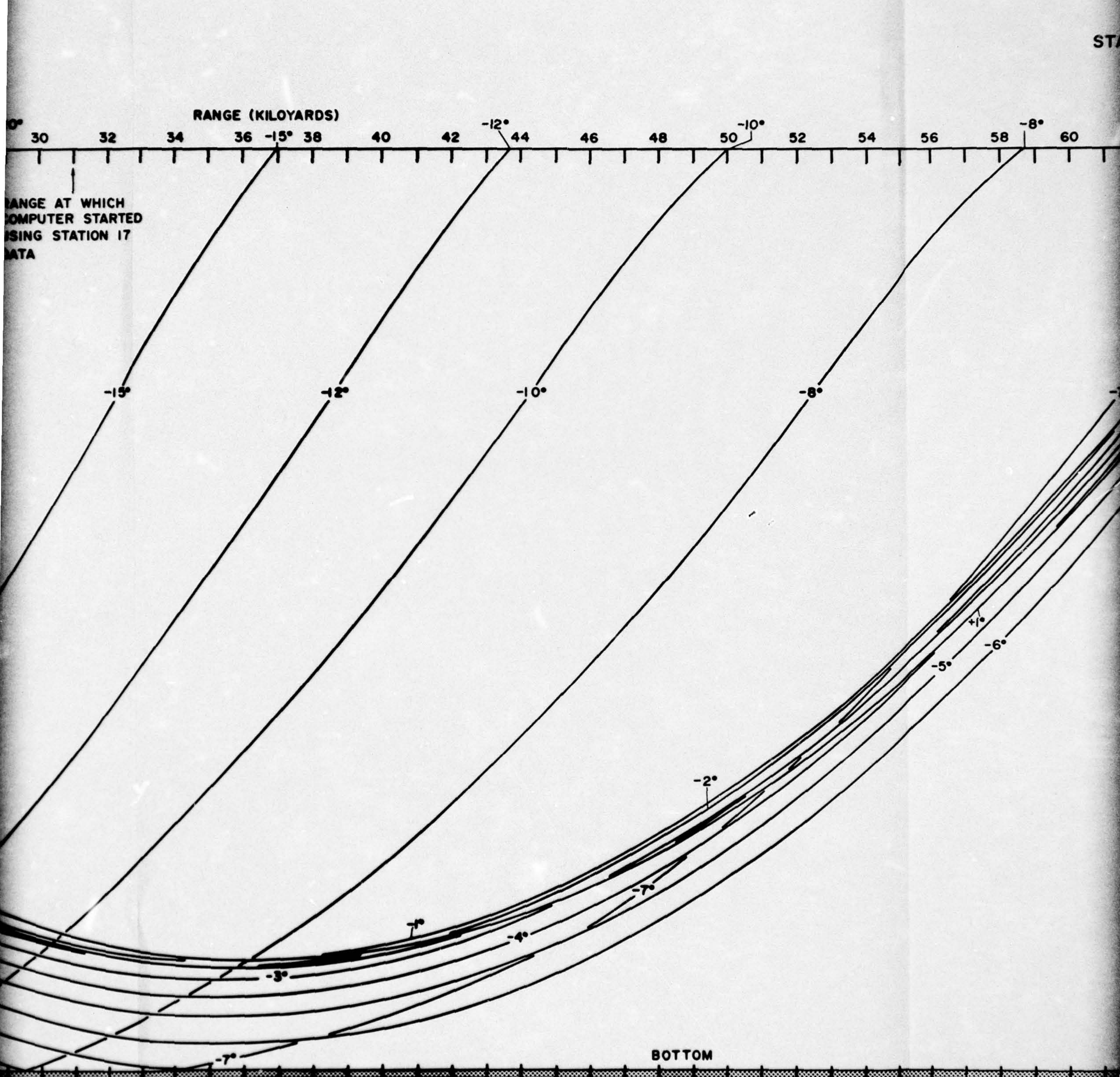
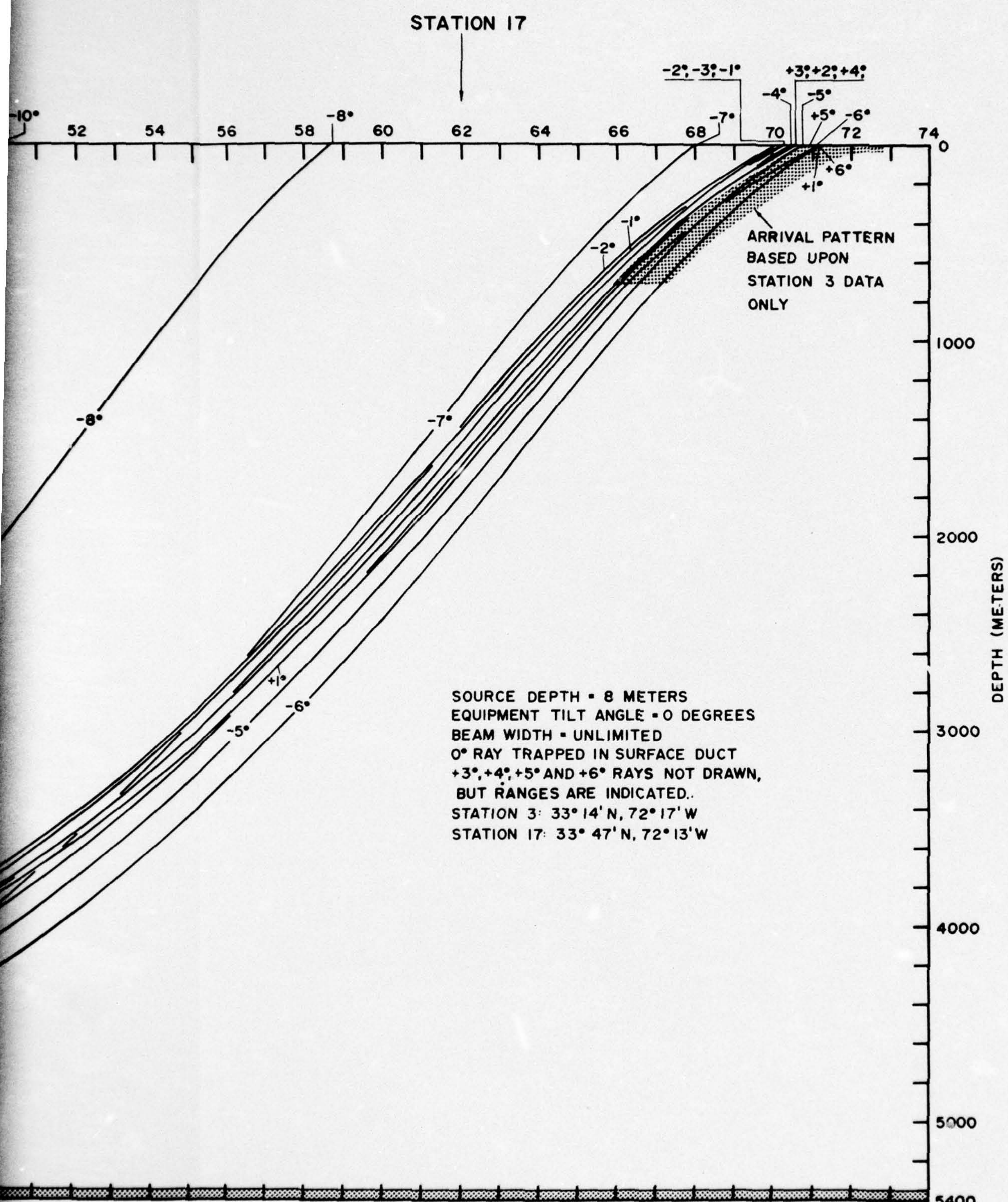


FIGURE 11 RAY DIAGRAM INCORPORATING HORIZ



Y DIAGRAM INCORPORATING HORIZONTAL CHANGES



STATION 17
-2°, -3°, -1°
+3°, +2°, +4°
-4°
-5°
+5°
-6°
-10°
-8°
-7°
52
54
56
58
60
62
64
66
68
70
72
74
0
+6°
+1°
-1°
-2°
ARRIVAL PATTERN BASED UPON STATION 3 DATA ONLY
1000
-8°
-7°
2000
DEPTH (METERS)
+1°
-6°
-5°
3000
SOURCE DEPTH = 8 METERS
EQUIPMENT TILT ANGLE = 0 DEGREES
BEAM WIDTH = UNLIMITED
0° RAY TRAPPED IN SURFACE DUCT
+3°, +4°, +5° AND +6° RAYS NOT DRAWN, BUT RANGES ARE INDICATED.
STATION 3: 33° 14' N, 72° 17' W
STATION 17: 33° 47' N, 72° 13' W
4000
5000
5400

4

is mounting to support the fact that small variations in the water column have pronounced effects on arrival patterns.

To obtain true depth from depth recorders operating in this area, the mean vertical sound speed was computed from the -80° bottom bounce ray (refraction is nil for an angle this steep). The distance from the source to the bottom along the ray path was divided by the travel time. To determine the error incurred in this approximation, one station was computed using a -89° ray as well as the -80° ray. The -89° ray produced a mean vertical sound speed of 0.1 meter per second smaller. (The computer program would not accommodate the -90° ray). This method of calculating the mean vertical sound speed is quicker and at least as accurate as the usual mathematical model which takes increments of depth and average sound speed over the increments, divides the depth by the sound speed, sums the resultant times, and divides the total time into the total depth to determine the resultant average vertical sound speed. A station location chart was annotated with the mean vertical sound speeds (Fig 12) and contoured. This representation showed a strong resemblance to the contours of temperature and salinity at both 500 and 800 meters. The significance of this similarity has not been determined.

In an attempt to find some meaningful acoustic relationships, various correlations were attempted. For example, the mean vertical sound speed to a given depth for each station was plotted against minimum range. Minimum range is the range from a source to the beginning of the convergence zone at the surface. The graph in Figure 13 A to D shows that there is an apparent linear correlation.

Another useful quantity to the sonar technician is the horizontal sound speed. It is calculated by dividing the horizontal range (the range along the surface from the source to the place where the ray strikes the surface or reaches minimum depth) by the travel time (the time from source, along the ray path, to the point of surfacing or reaching minimum depth). The horizontal sound speeds to the minimum ranges were plotted, contoured (Fig 14), and compared with the temperature contours at 500 and 800 meters; there was a fairly good correlation.

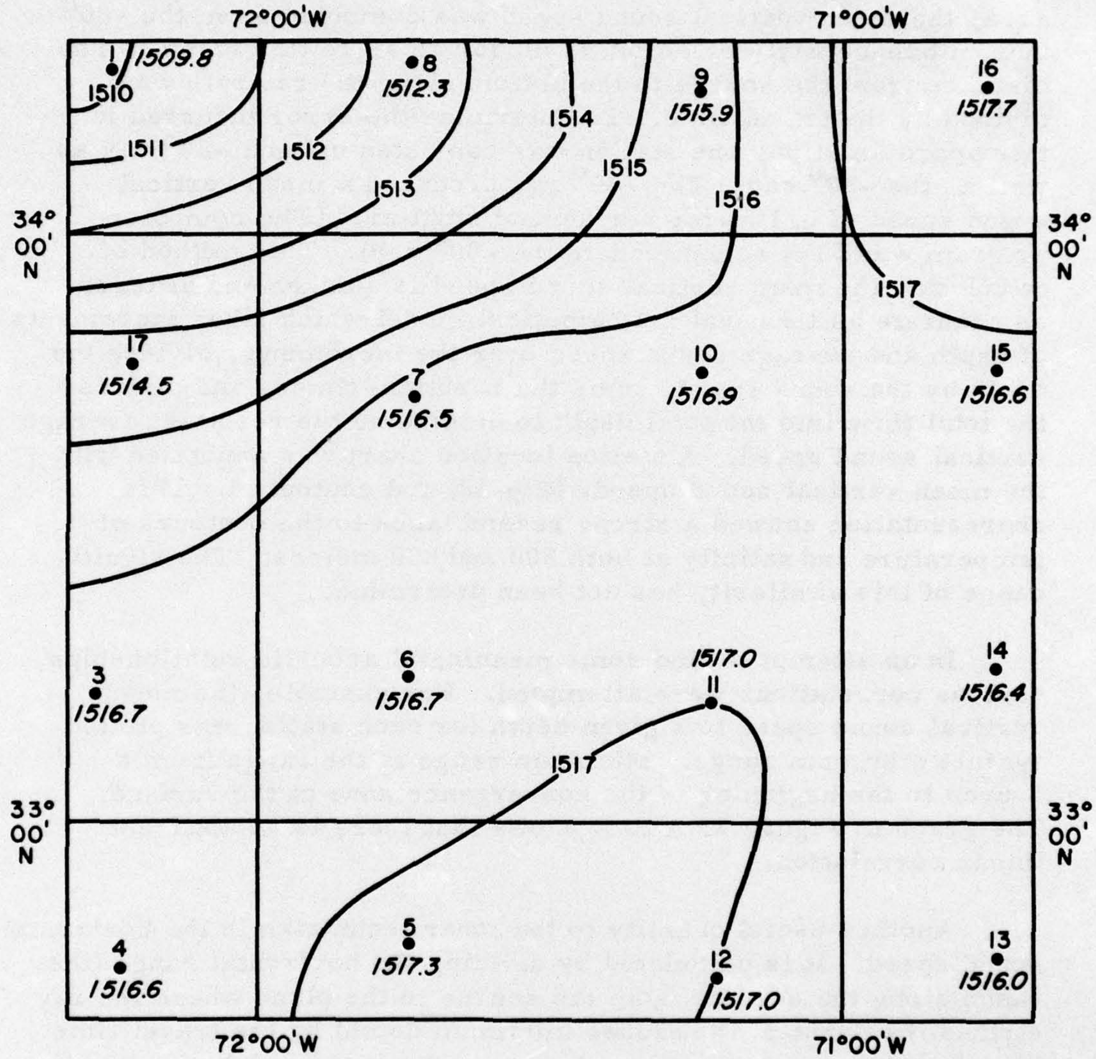


FIGURE 12 MEAN VERTICAL SOUND SPEED

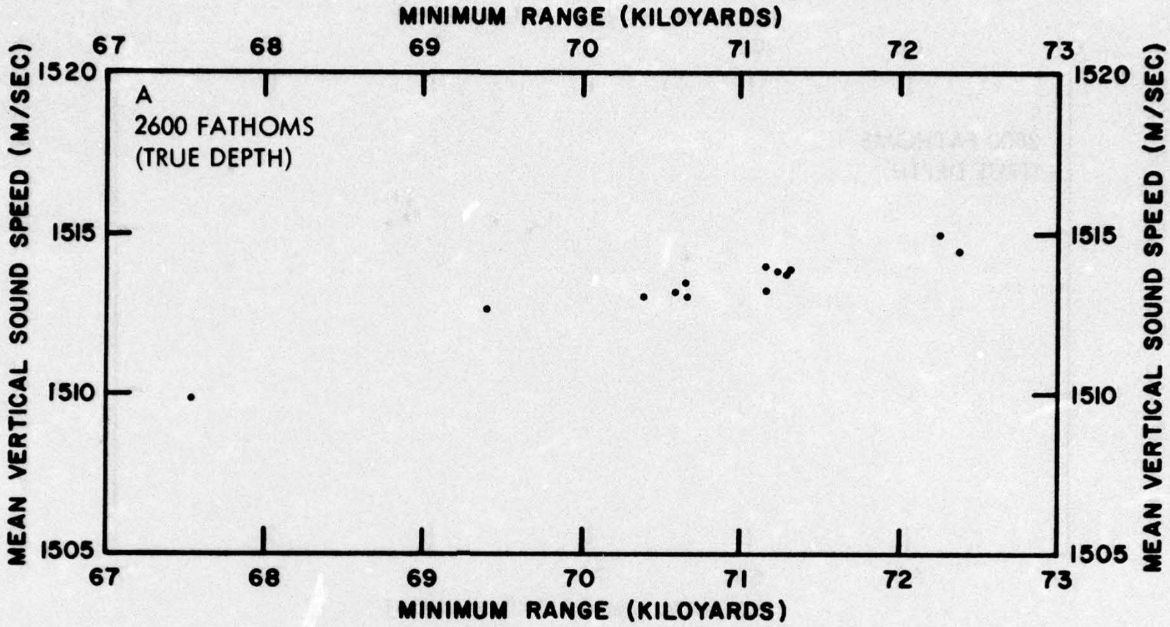


FIGURE 13a MEAN VERTICAL SOUND SPEED VS. MINIMUM RANGE TO CONVERGENCE ZONE

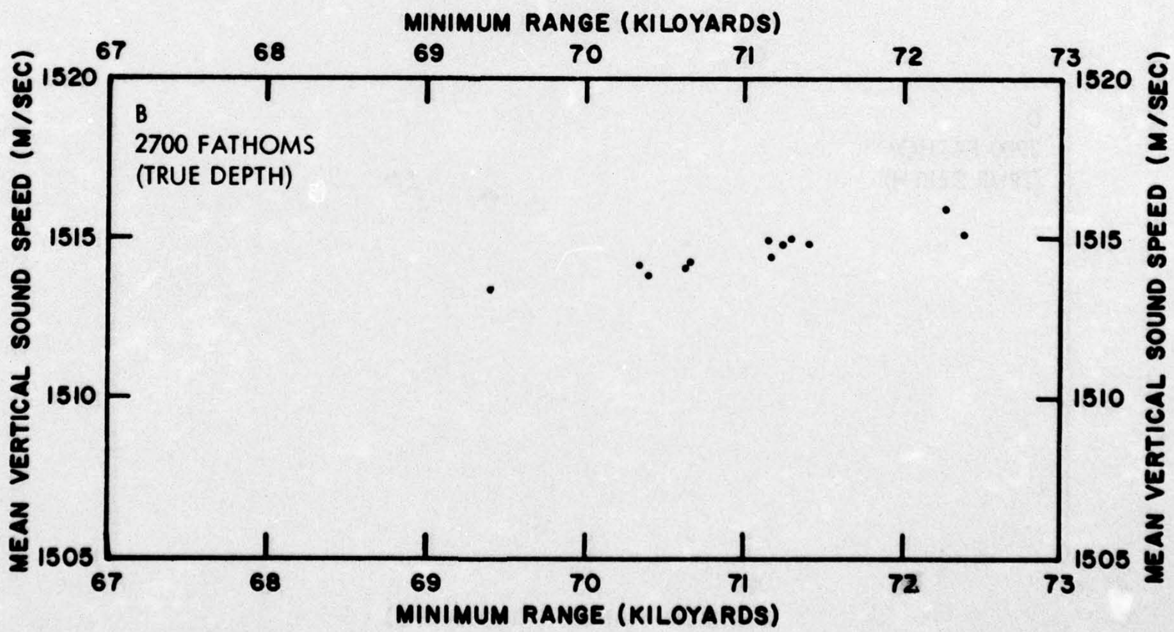


FIGURE 13b MEAN VERTICAL SOUND SPEED VS. MINIMUM RANGE TO CONVERGENCE ZONE

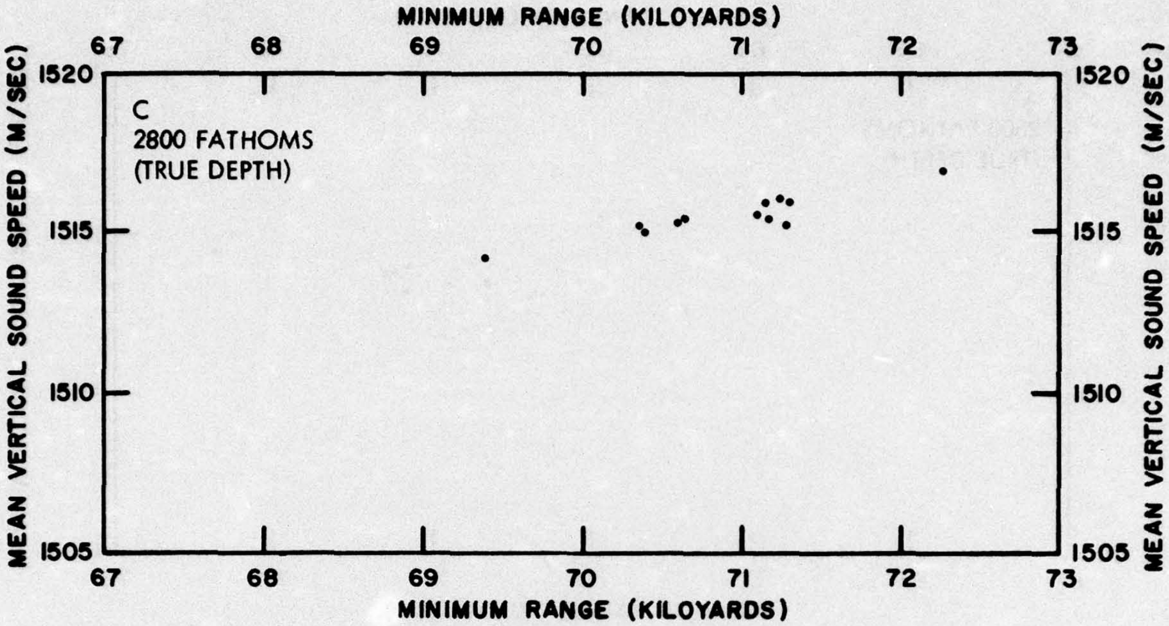


FIGURE 13c MEAN VERTICAL SOUND SPEED VS. MINIMUM RANGE TO CONVERGENCE ZONE

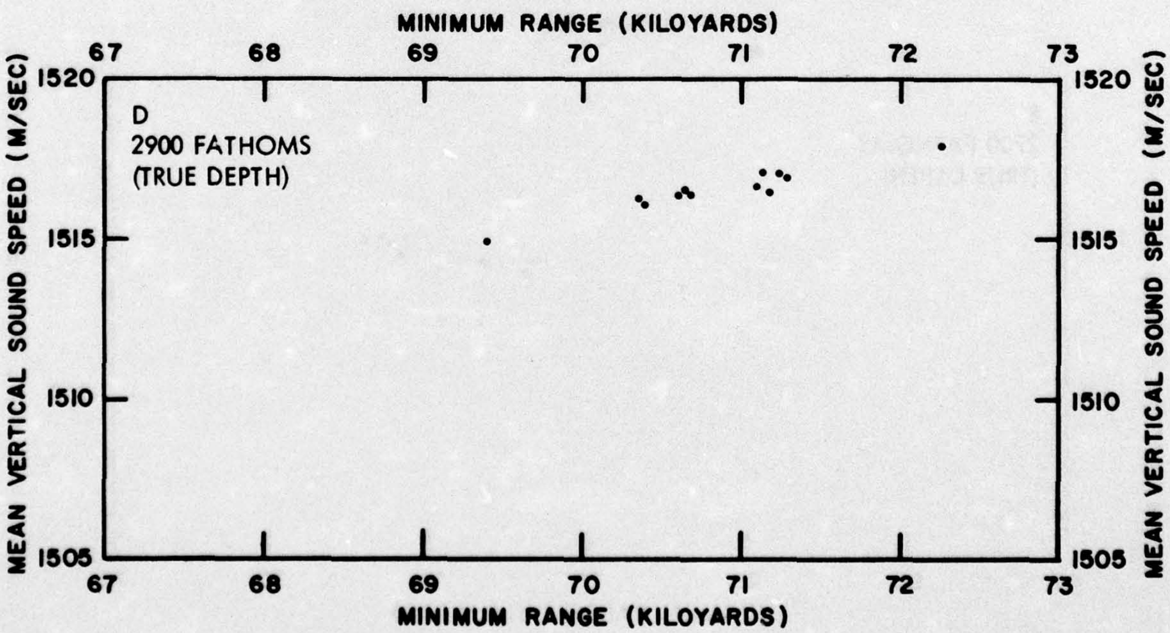


FIGURE 13d MEAN VERTICAL SOUND SPEED VS. MINIMUM RANGE TO CONVERGENCE ZONE

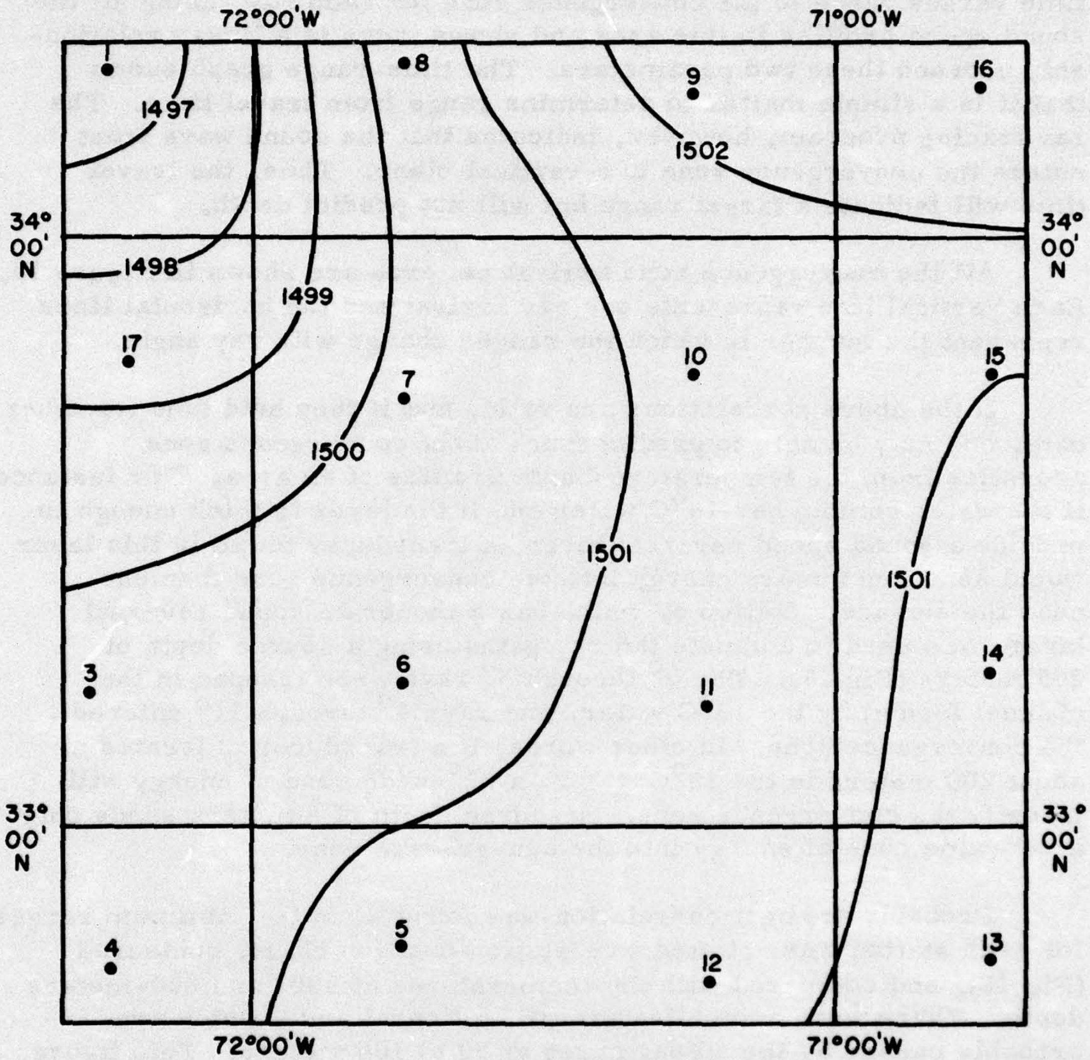


FIGURE 14 HORIZONTAL SOUND SPEED TO MINIMUM RANGE IN CONVERGENCE ZONE

Instead of using horizontal sound speed to determine range from the travel time, the travel time may be used directly when using the convergence zone mode of propagation. Figure 15 is a graph of travel time versus range to the convergence zone for each ray, using all the sound speed profiles in this area and shows there is a linear relationship between these two parameters. The time-range graph shows that it is a simple matter to determine range from travel time. The ray tracing program, however, indicates that the sound wave front enters the convergence zone in a vertical plane. Thus, the travel time will indicate a target range but will not predict depth.

All the convergence zone arrival patterns are shown in Figure 16. Each vertical line represents one ray arrival and the horizontal lines represent the manner in which the ranges change with ray angle.

If the above correlations are valid, and if they hold true for other data, one may be able to predict much about convergence zone acoustics from the temperature-depth profiles of an area. For instance, if the water column has 18°C water and if the layer is thick enough to provide a sound speed reversal layer, a transducer towed in this layer would send much more energy into the convergence zone than one near the surface. Station 5, which has a moderate sound reversal layer, was used to compute the ray paths using a source depth of 205 meters (Fig 17). The 0° through 3° rays were trapped in the channel formed by the 18°C water, and rays 4° through 11° entered the convergence zone. In other words, if a transducer is located at about 200 meters in the 18°C water, a 22°-wide cone of energy will insonify the convergence zone. A source depth of 8 meters sends only a 14°-wide cone of energy into the convergence zone.

Probably the best correlation was found when the minimum ranges for each station were plotted on a station location chart, contoured (Fig 18), and compared with the temperatures at 500- and 800-meters depth. There were anomalies around Stations 3 and 9 which are probably caused by the strong gyres at 50 to 100 meters. This figure indicates that, exclusive of strong, near-surface features, an increase in the depth of the thermocline causes an increase in minimum range. The fact that these near-surface features do apparently affect the minimum range is a complicating factor, but the minimum range may be predictable (within about 1000 yards) from the depth of the thermocline or the temperature at a particular depth in the thermocline.

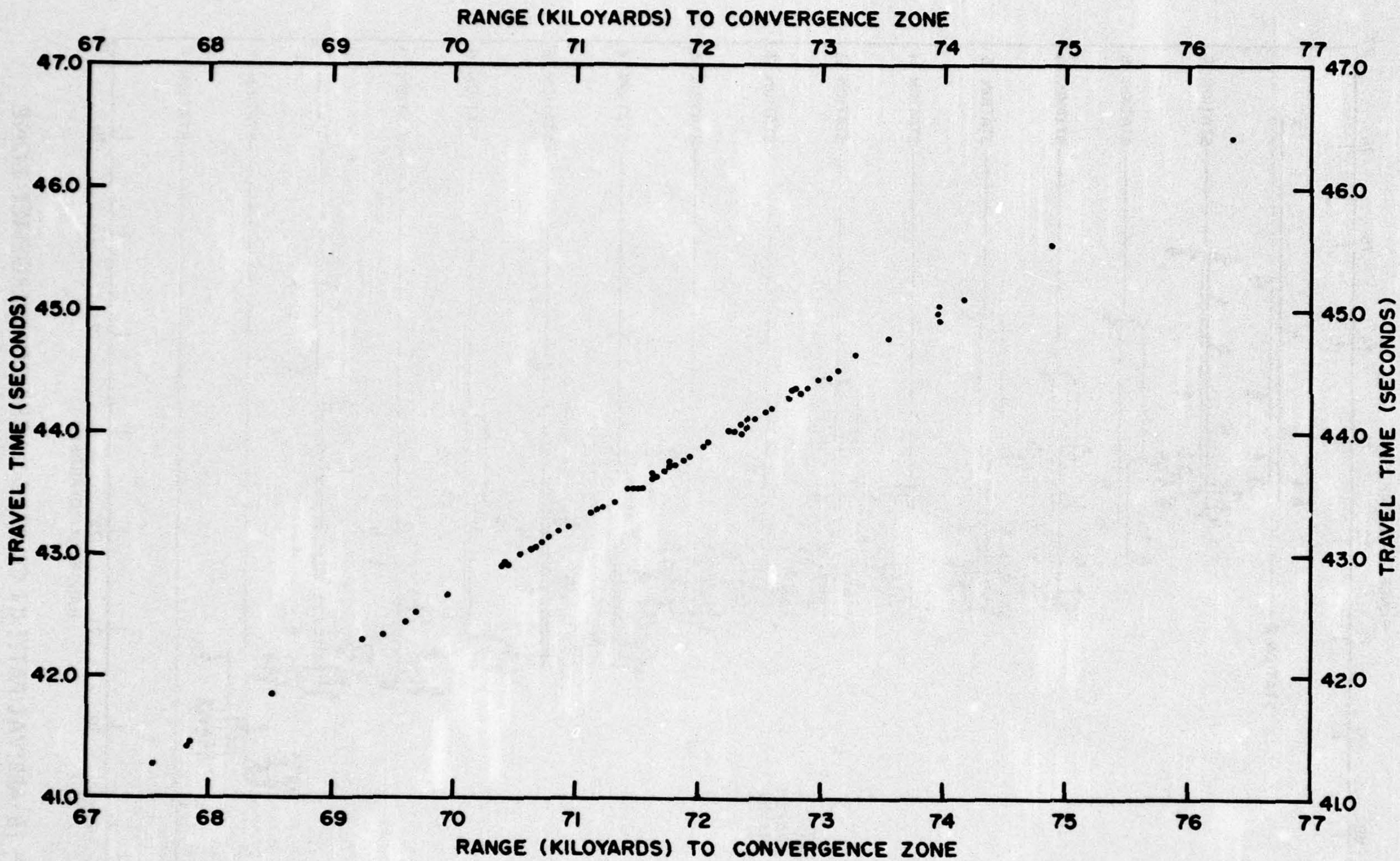


FIGURE 15 TRAVEL TIME VS. RANGE TO CONVERGENCE ZONE

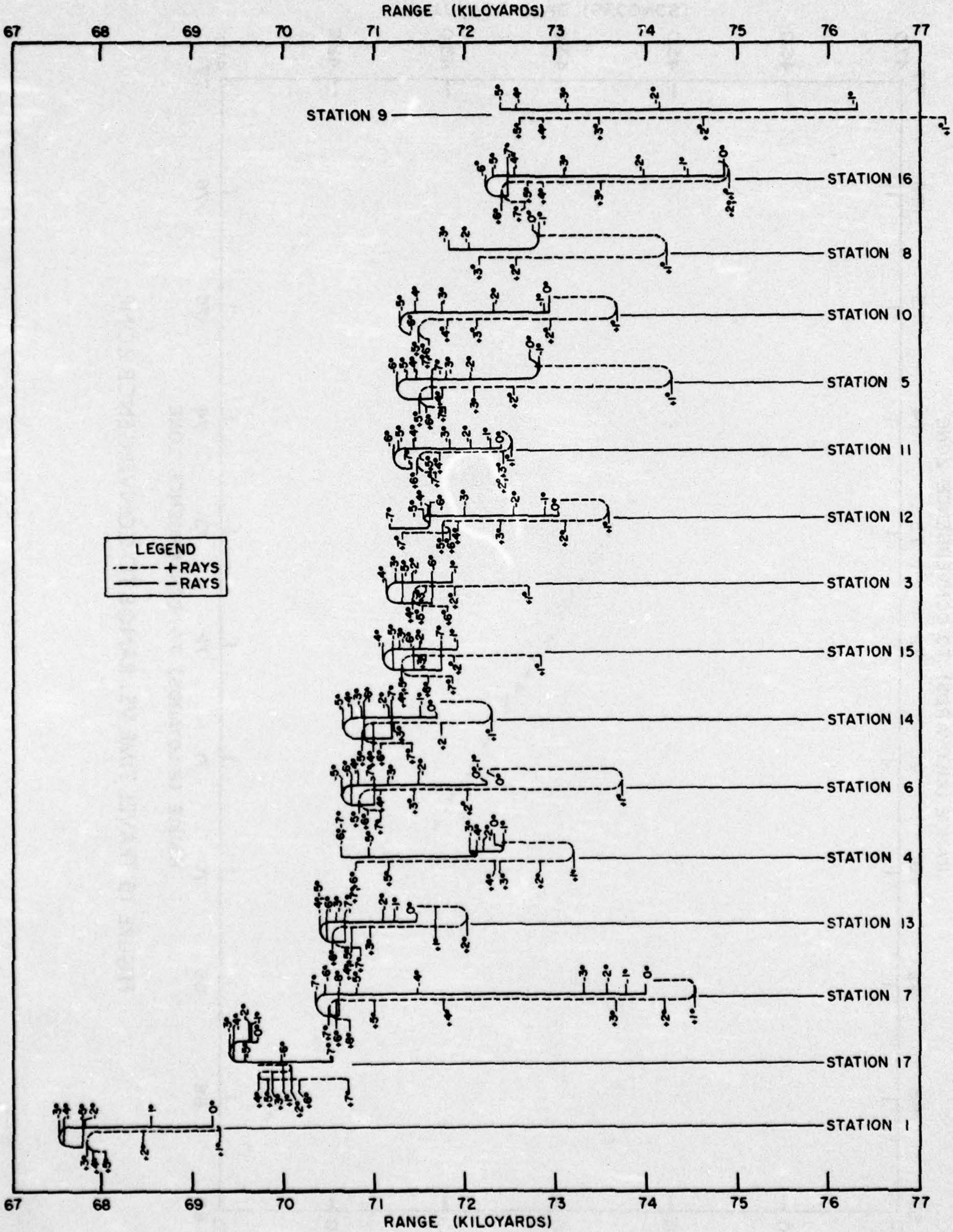


FIGURE 16 ARRIVAL PATTERN OF RAYS IN THE CONVERGENCE ZONE

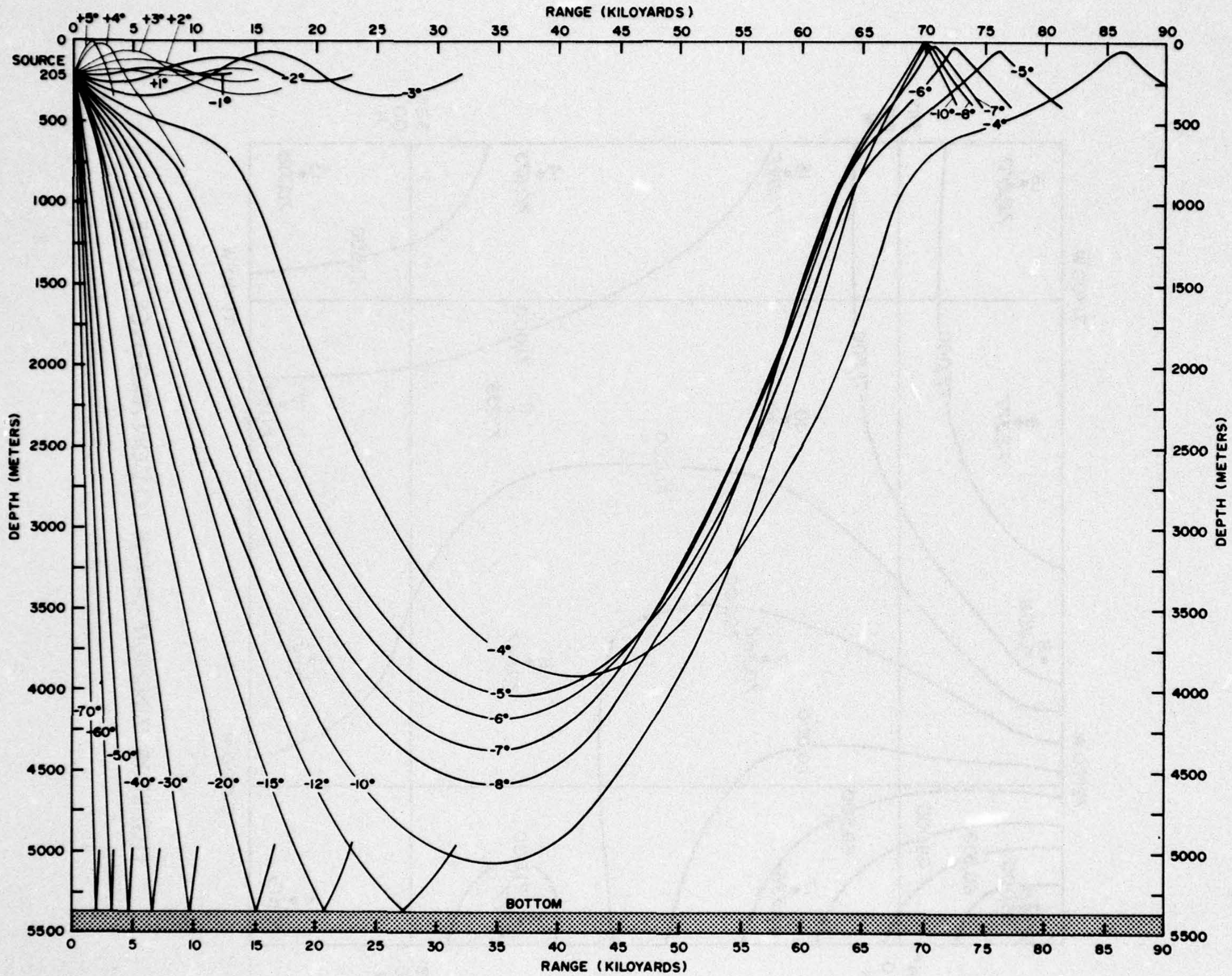


FIGURE 17 RAY DIAGRAM WITH SOURCE LOCATED IN 18°C WATER

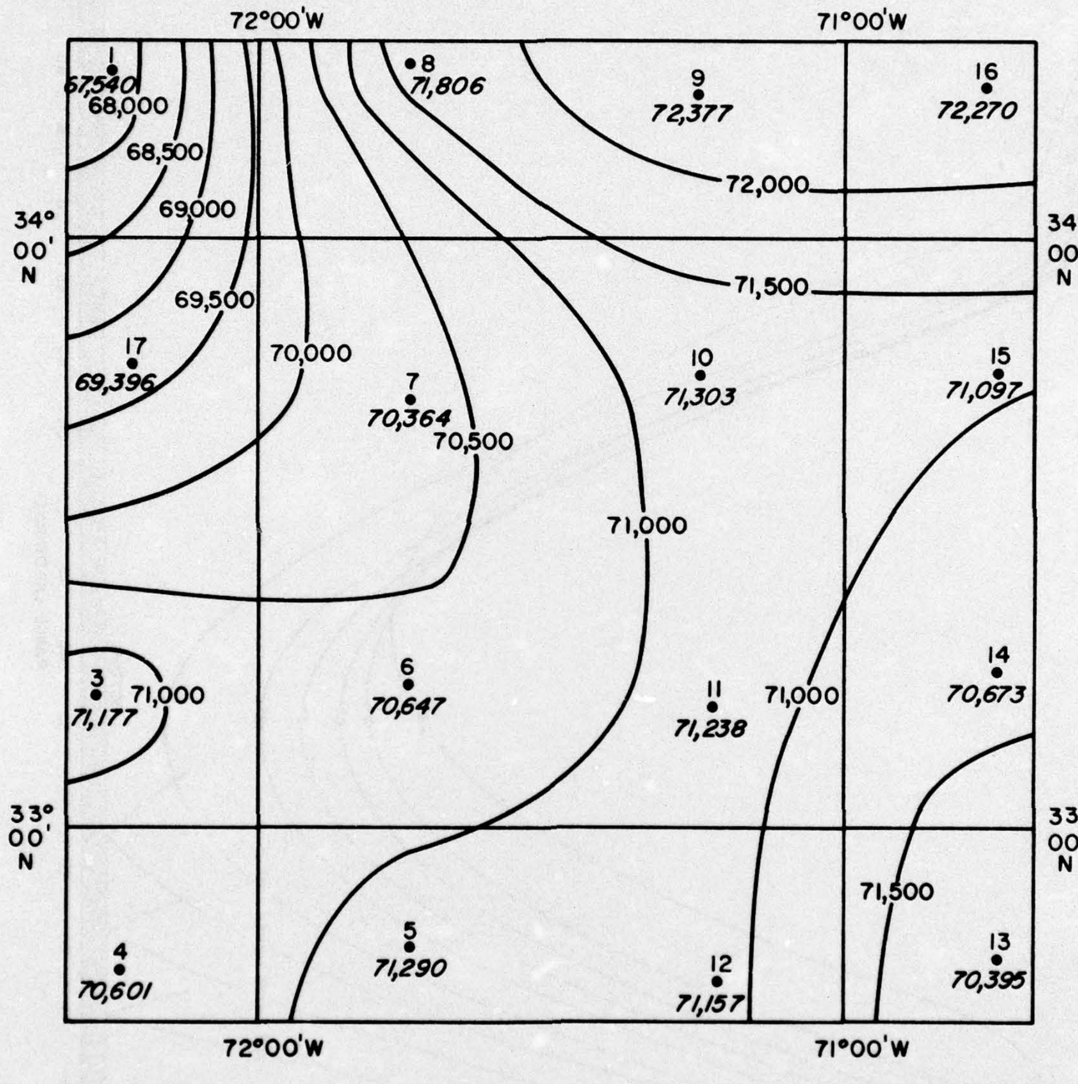


FIGURE 18 MINIMUM RANGE TO CONVERGENCE ZONE

CONCLUSIONS

The survey of area C_1 showed that there were significant oceanographic differences in a one-degree square in the ocean in a one-week period. These differences are present because the area is within the influence of the Gulf Stream. This survey seems to demonstrate that a single oceanographic station cannot adequately represent a one-degree square, at least in this region, much less a larger area.

The data showed 14 of the stations grouped together on the temperature-depth and salinity-depth composites because of properties similar to the Sargasso Sea Water, while the other 2 stations differed considerably; exhibiting properties of Gulf Stream Water.

The temperature and salinity contours at 500- and 800-meter depths show that the effect of the 2 northwestern stations is spread throughout most of the area. Also, it is noteworthy that the regional effect of these stations does not come into play above 300 meters, but acts on the permanent thermocline. Since these 2 stations resemble Gulf Stream Water, it is probable that a gyre formed from a meander in the Gulf Stream migrated into area C_1. It is also possible that some other process might have altered or removed the 18°C water from the water column in this portion of the area.

A series of observations designed to survey an area oceanographically and carried out by one ship using standard Nansen techniques does not separate the time from the geographical variations in the area, unless special measures are taken to sample the time variations during the survey. The only conventional method of doing this is by the BT. Unfortunately, the limiting depth of this instrument is 900 feet, which is somewhat above the permanent thermocline.

Most of the variations in the seasonal thermocline were either gradual or periodic; however, the northeasternmost station showed a 3°C change in temperature over a period of 5 hours. This was part of a change in water shown by a 100-foot drop of the 70°F (21°C) isotherm in 8 hours and was apparently caused by the inflow of a different kind of water in the near-surface layer.

Upon comparison of the BT traces with the Nansen temperature records of all stations, two ranges of minimum difference appeared between the BT traces. The upper range was at the surface and the

lower between 150 and 200 meters, varying in depth from station to station. These differences showed that the temperature-depth profiles vary in a manner similar to a standing wave. The maximum difference was at 30 meters, for most stations, where the thermocline was the steepest. Most differences observed would correspond to small vertical variations in the thermocline. It is interesting to note that there was little temperature variation at the surface even though time and station location changed. The lower minimum difference area was used in an attempt to calibrate the BT relative to the reversing thermometers, but the calibration factor was not considered accurate.

Both the station with the coldest seasonal thermocline (the northwesternmost station) and the station with the warmest thermocline (a north-central station) were selected and an envelope of time variations around each station was plotted. These time variations were found to be of limited extent while the geographical variations, those due to station location, were much larger and probably caused by a process similar to that occurring at the northeasternmost station when the Nansen cast was made.

The sound speed profiles displayed two sound reversal layers; one was in the isothermal 18°C water and one below the permanent thermocline. A source located in the 18°C water reversal layer can put a much wider cone of energy into the convergence zone than does one located at the surface.

The time-range correlation showed that the range is linearly proportional to the travel time when considering convergence zone. This is true because there is only a slight difference between the range and the slant path distance; the range can be used as an approximation of the slant path distance.

Another useful comparison is between the minimum range to the convergence zone and the temperature at 500- and 800-meter depths. This comparison showed that the minimum range depended on the depth of the permanent thermocline with near surface anomolies complicating the pattern. Apparently, the minimum range may be predictable (within 1000 yards) from a knowledge of the depth of the permanent thermocline or the temperature at a particular depth in the thermocline.

The largest difference in minimum range to the convergence zone for all stations in the area was about 5000 yards, which occurred between the northwest station and the two northeastern stations. This is a very large variation to be occurring over a range of 60 nautical miles. Such a variation is similar to that found across a boundary and thus, is not representative of the whole area. A more representative difference would be the 2000-yard change in minimum range, exclusive of the northwestern stations. It also must be borne in mind that the assumption that one station can be used to represent the oceanic conditions from the source to the convergence zone is invalid. A more realistic representation would be one in which the seasonal and short period changes are taken into account statistically and applied to what is already known about the area.

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